DEPARTMENT OF THE ARMY
KANSAS CITY DISTRICT, CORPS OF ENGINEERS
700 FEDERAL BUILDING
KANSAS CITY, MISSOURI 64106-2896

REPLY TO
ATTENTION OF

February 8, 2009

Project Management
Environmental Branch

Mr. Jesse Scott
Missouri Department of Natural Resources
Federal Facilities Section, HWP
1730 E. Elm Street
Jefferson City, MO 65101

Dear Mr. Scott,

The U.S. Army Corps of Engineers, Kansas City District is pleased to submit two copies of the Draft Final Feasibility Study Report for the former Hanley Area at the St. Louis Ordnance Plant in St. Louis, Missouri. Additional copies have been distributed as noted below. Receipt of your written comments to me by March 26, 2010 is greatly appreciated.

If you have any questions regarding this submittal, please do not hesitate to contact me at (816) 389-3912.

Sincerely,

Josephine Newton-Lund
Senior Project Manager

Cc: Mr. Jonathan Harrington, U.S. Army Environmental Command – 1 hard copy
Ms. Lisa Gulbranson, 88th Regional Support Command – 1 electronic copy
Mr. Dave Moore, 88th Regional Support Command – 1 electronic copy
Mr. Barry McFarland, 88th Regional Support Command – 1 hard copy
Mr. Jim Brown, Sverdrup Army Reserve Center – 1 hard copy
Ms. Michelle Hartman, Missouri Department of Health and Senior Services – 1 hard copy
Mr. Matt Jefferson, U.S. Environmental Protection Agency Region VII – 1 hard copy
Mr. Bill Pedicino, U.S. Environmental Protection Agency Region VII – 1 hard copy
Mr. Filippe Cade, Professional Environmental Engineers – 1 hard copy

Draft Final Feasibility Study Report

St. Louis Ordnance Plant Former Hanley Area

St. Louis, Missouri

Prepared for:

US Army Corps of Engineers
Kansas City District

88th Regional Support Command

Prepared by: Conti and CH2MHILL

February 2010

STATEMENT OF TECHNICAL REVIEW

Performance Work Statement for
Environmental Remediation Services at the Former Hanley Area
St. Louis Ordnance Plant, Missouri

Feasibility Study Report, St. Louis Ordnance Plant, Former Hanley Area

The Conti/CH2M HILL Team has completed the technical review of the draft final submittal of the Feasibility Study Report. Notice is hereby given that an independent technical review has been conducted that is appropriate to the level of risk and complexity inherent in the project, as defined in the Quality Control Plan. During the independent technical review, compliance with established policy principles and procedures, utilizing justified and valid assumptions, was verified. This included review of assumptions; methods, procedures and material used in analyses; the appropriateness of data used and level of data obtained; and reasonableness of the results including whether the product meets the customer's needs consistent with the law and existing USACE policy.

Technical Reviewer	Signature	Date of Review
Catherine Barnett		01/28/10

Quality Control System Manager (for QCP) or Project Manager	ITR Leader
Luis Seijido	Catherine Barnett
Signature	Signature

Draft Final Feasibility Study Report

St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

Prepared for
U.S. Army Corps of Engineers,
Kansas City District
Contract No. W912DQ-05-D-0002
Task Order No. 0007

February 2010

Prepared by

Conti

and

CH2MHILL

Executive Summary

This feasibility study report develops and evaluates remedial alternatives for the former Hanley Area of the St. Louis Ordnance Plant in St. Louis, Missouri, as part of the Defense Environmental Restoration Program. The report was prepared for the U.S. Army Corps of Engineers-Kansas City District under Contract Number W912DQ-05-D-0002, Task Order Number 0007. A remedial investigation was performed at the St. Louis Ordnance Plant, former Hanley Area (CH2M HILL 2009a) to investigate and characterize the extent and fate and transport of contamination, to assess risk posed to human health and the environment, and to identify the chemicals requiring further action.

Several areas of elevated lead, arsenic, and Aroclor 1260 concentrations in surface soil were identified at the site. A decision was made to remove these soils, eliminating the need for a human health risk assessment for these soils as part of the remedial investigation. Evaluation of the rest of the site data identified unacceptable human health risks for (1) future exposures to soil by residents in 4 of 12 exposure units; (2) future offsite exposure to groundwater by residents; and (3) future onsite exposures to groundwater by residents and construction workers. The chemicals of concern in soil are antimony and thallium; those in groundwater are primarily chlorinated volatile organic compounds. In addition, vapor from shallow groundwater may enter indoor air of future onsite residences or current offsite residences. Therefore, future indoor air exposures within buildings constructed in the area may be at unacceptable levels because of high concentrations detected and shallow groundwater depths. Risks to ecological receptors were found to be negligible.

The object of the feasibility study was to develop and evaluate remedial alternatives that address potential unacceptable risks to human health and the environment and meet applicable or relevant and appropriate requirements. Remedial action objectives were established based on regulatory requirements, standards, and guidance. General response actions were identified for the site to develop remedial alternatives. Based on the risks present at the site, the following alternatives were developed: Alternative 1, No Action; Alternative 2, In Situ Groundwater Treatment using Thermal Technologies, Soil and Powder Well Sediment Removal, and Offsite Disposal ; Alternative 3, In Situ Groundwater Treatment and Soil and Powder Well Sediment Removal and Offsite Disposal ; and Alternative 4, Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal, and Offsite Disposal. The alternatives were evaluated against seven feasibility evaluation criteria as defined in the National Contingency Plan and the Comprehensive Environmental Response, Compensation and Liability Act. Alternative 1 does not meet the evaluation criteria. Alternatives 2, 3, and 4 meet the threshold criteria of protectiveness and compliance with applicable or relevant and appropriate requirements and were evaluated following the evaluation criteria. The preferred alternative will be presented in the Proposed Plan, which will be released to the public for review and comment. Public input on the alternatives is paramount in the selection process. The preferred alternative may be modified based on the comments received.

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Tables

Figures

Acronyms and Abbreviations

ARAR	applicable or relevant and appropriate requirement
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
COC	chemical of concern
CT	carbon tetrachloride
cVOC	chlorinated volatile organic compound
1,2-DCA	1,2-dichloroethane
DCE	dichloroethene
DNAPL	dense nonaqueous phase liquid
Eco-SSL	ecological soil screening level
ERH	electrical resistance heating
FS	feasibility study
GRA	general response action
HHRA	human health risk assessment
HI	hazard index
MCL	maximum contaminant level
MDHSS	Missouri Department of Health and Senior Services
MDNR	Missouri Department of Natural Resources
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MLE	maximum-likelihood-estimate
NAPL	nonaqueous phase liquid
NCP	National Contingency Plan
O&M	operation and maintenance
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PRG	preliminary remediation goal
RAO	remedial action objective
RI	remedial investigation
SVE	soil vapor extraction
TCA	trichloroethane
TCE	trichloroethene
TCH	thermal conductive heating
TeCA	tetrachloroethene
TTZ	target treatment zone
USACE	United States Army Corps of Engineers
USAEC	United States Army Environmental Command
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound
ZVI	zero valent iron

1. Introduction

A feasibility study (FS) was conducted to develop and evaluate remedial alternatives for the former Hanley Area of the St. Louis Ordnance Plant, in St. Louis, Missouri. This report was prepared for the U.S. Army Corps of Engineers (USACE), Kansas City District, as part of the Defense Environmental Restoration Program under Contract Number W912DQ-05-D-0002, Task Order Number 0007.

1.1 Regulatory Framework

The U.S. Army is the lead agency for the former Hanley Area. The U.S. Army Environmental Command (USAEC) is the Army agency responsible for cleanup activities at the site. The USACE-Kansas City District manages the environmental cleanup at the former Hanley Area on behalf of the USAEC. Through a U.S. Department of Defense State Memorandum of Agreement, USACE works with the Federal Facilities section of Missouri Department of Natural Resources (MDNR) on Defense Environmental Restoration Program properties in Missouri. U.S. Environmental Protection Agency (USEPA) Region 7 provides regulatory assistance to MDNR. Although the former Hanley Area is not on the National Priorities List, USACE follows the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process for responses to hazardous substances, pollutants, and contaminants as set forth in the at 10 U.S. Code 2701.

1.2 Site Setting

The former Hanley Area consists of 14 acres and is located on the western boundary of the city limits of St. Louis, 0.25 mile south of the intersection of I-70 and Goodfellow Boulevard (Figure 1-1). The former Hanley Area (Army Reserve Facility ID MO030, 6400 Stratford Avenue) is adjacent to the northern part of the Sverdrup U.S. Army Reserve Center (Facility ID MO028), located at 4301 Goodfellow Boulevard in St. Louis. The 89th Regional Readiness Command owned the former Hanley Area until it was disestablished in June 2009. The 88th Regional Support Command (RSC) owns the former Hanley Area and occupies the Center. The entire site, as described by the St. Louis City Zoning Department, is zoned industrial, commercial, and residential. Commercial properties border the site to the west, south, and east. Privately owned residential properties are adjacent to the site to the north.

The site consists of a relatively flat terrace that slopes steeply down to Goodfellow Boulevard to the east and Stratford Avenue on the north. The site elevation ranges from 532 to more than 558 feet. An elevation change (greater than 18 feet) occurs between the northern part of the site and Stratford Avenue (Figure 1-2).

In 2005, the St. Louis Planning Commission adopted a strategic land use plan for the City of St. Louis. The plan provides a path forward for future development. It identifies established neighborhoods, historic districts, and business areas that the City intends to maintain and enhance. It also identifies areas where future development and land use changes are encouraged. The St. Louis Strategic Land Use Plan identifies the former Hanley Area as a "business and industrial development area." Neighboring parcels to the south and east are designated similarly. Residential properties to the north of the former Hanley Area, across Stratford Avenue, are designated a "neighborhood preservation area." Parcels north of the former Hanley Area that lie along Goodfellow Boulevard are designated a "neighborhood commercial area" (St. Louis Planning and Urban Design Agency 2009). Although the General Services Administration and 88th Regional Support Command do not have immediate plans for developing the property, the City of St. Louis has expressed interest in obtaining and redeveloping the former Hanley Area in the future.

As described below, buildings and bunkers at the Hanley Area have been demolished with the exception of Buildings 219A, 219D, 219G, and 236. According to the 88th RSC, Buildings 219A, 219D, and 236 are used for storage only. Building 219G is occupied during business hours, and the site is completely fenced (partially with iron fencing, the balance with a 6-foot-tall chain-link fence).

1.3 Site History

The St. Louis Ordnance Plant operated from 1941 to 1945 as a small arms ammunition production facility, producing primarily .30 and .50 caliber ammunition. The plant was divided into two areas designated No. 1 (east of Goodfellow Boulevard) and No. 2 (west of Goodfellow Boulevard). Plant Area No. 2 encompassed 27.68 acres. The former Hanley Area consists of the 14.68 acres at the northeastern end of Plant Area No. 2 at the intersection of Stratford Avenue and Goodfellow Boulevard (Figure 1-2). Production there consisted of blending of primary explosives, incendiary compounds, and the tracer charging of .30 and .50 caliber projectiles as part of the assembly of the final product. Powder wells installed in 1941 received wastewater from buildings and magazines until 1945. The powder wells provided sediment collection before the wastewater was discharged to the sanitary sewer.

From 1945 through 1959, the U.S. Army Adjutant General's Office used some buildings within Plant Area No. 2 to maintain service records. The Department of Defense Finance Center used other buildings within Plant Area No. 2 as classrooms.

The Hanley Area takes its name from Hanley Industries, Inc., which leased it in 1959 and conducted operations there through 1979. Hanley used the site for research, development, manufacture, and testing of explosives. Over that time, Hanley produced specialty ordnance and nonordnance devices for the U.S. military and the National Aeronautics and Space Administration. Hanley used most of the buildings to load detonators and primers and to mix explosives. Explosives were dried in magazines by leaving cans of explosives exposed to the air, and a lead azide reactor was operated in one of the magazines, the location of which is unknown. Hanley reportedly did not use the powder wells or sumps on the property for wastewater disposal.

The Goodfellow U.S. Army Reserve Center (now Sverdrup U.S. Army Reserve Center) was established on the remaining 13 acres of Plant Area No. 2. Some of the western parts of the 13 acres subsequently were transferred to the U.S. Department of Labor and are occupied by the Job Corps Training Center. Most of the Hanley Area housed a series of warehouse buildings, bunkers, and related buildings. Between 2004 and 2007, buildings and bunkers, with the exception of Buildings 219A, 219D, 219G, and 236 were demolished by an 88th Regional Support Command (formerly known as the 89th Regional Readiness Command) contractor.

The site contains underground rooms (former basements and bunkers), tunnels for service utilities, and a combined underground wastewater and stormwater collection system. The underground structures are still intact. According to the October 2001 Preliminary Assessment/Site Inspection Report (TapanAm 2001), very little water was observed in the tunnel system located south of former Building 220. The tunnels are located 10 to 12 feet below ground (U.S. Army Toxic and Hazardous Materials Agency 1991).

1.4 Site Investigations

Various investigations were conducted at the former Hanley Area since 1980. Information regarding the site investigations is available in the following documents:

- Investigation of Explosives and Metals, U.S. Army Toxic and Hazardous Materials Agency, 1981
- Environmental Study, U.S. Army Toxic and Hazardous Materials Agency, 1991
- Site Investigation, HARZA Environmental Services, Inc., 1998
- Preliminary Assessment/Site Inspection, TapanAm Associates, Inc., 2001
- Phase I Environmental Site Assessment, Pangea, 2003
- Phase II Environmental Site Assessment, Shaw Environmental, 2003
- Sampling to support demolition activities, SCS Engineers, 2004
- Phase I Remedial Investigation (RI), USACE, 2005 through 2007
- RI, CH2M HILL, 2009

1.5 Objectives and Scope

According to the USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final* (1988) and the National Contingency Plan (NCP), an FS is conducted by developing remedial alternatives, screening those alternatives to reduce the number, and analyzing selected alternatives in detail. The object of an FS is to develop and evaluate alternatives that will address potential unacceptable risk to human health and the environment and to satisfy applicable or relevant and appropriate requirements (ARARs). The following steps were used to develop and evaluate remedial alternatives for the former Hanley Area:

1. Identify ARARs.
2. Develop remedial action objectives (RAOs).
3. Determine preliminary remediation goals (PRGs) and areas exceeding the PRGs.
4. Evaluate chemicals of concern (COCs) against remediation goals.
5. Develop general response actions (GRAs).

6. Develop and screen technologies and process options.
7. Develop remedial alternatives.
8. Perform detailed analysis of remedial alternatives.
9. Perform comparative analysis of each alternative's ability to satisfy the evaluation criteria.

N

0 300 600
Feet

LEGEND

Site Boundary

FIGURE 1-1
SITE LOCATION MAP
St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

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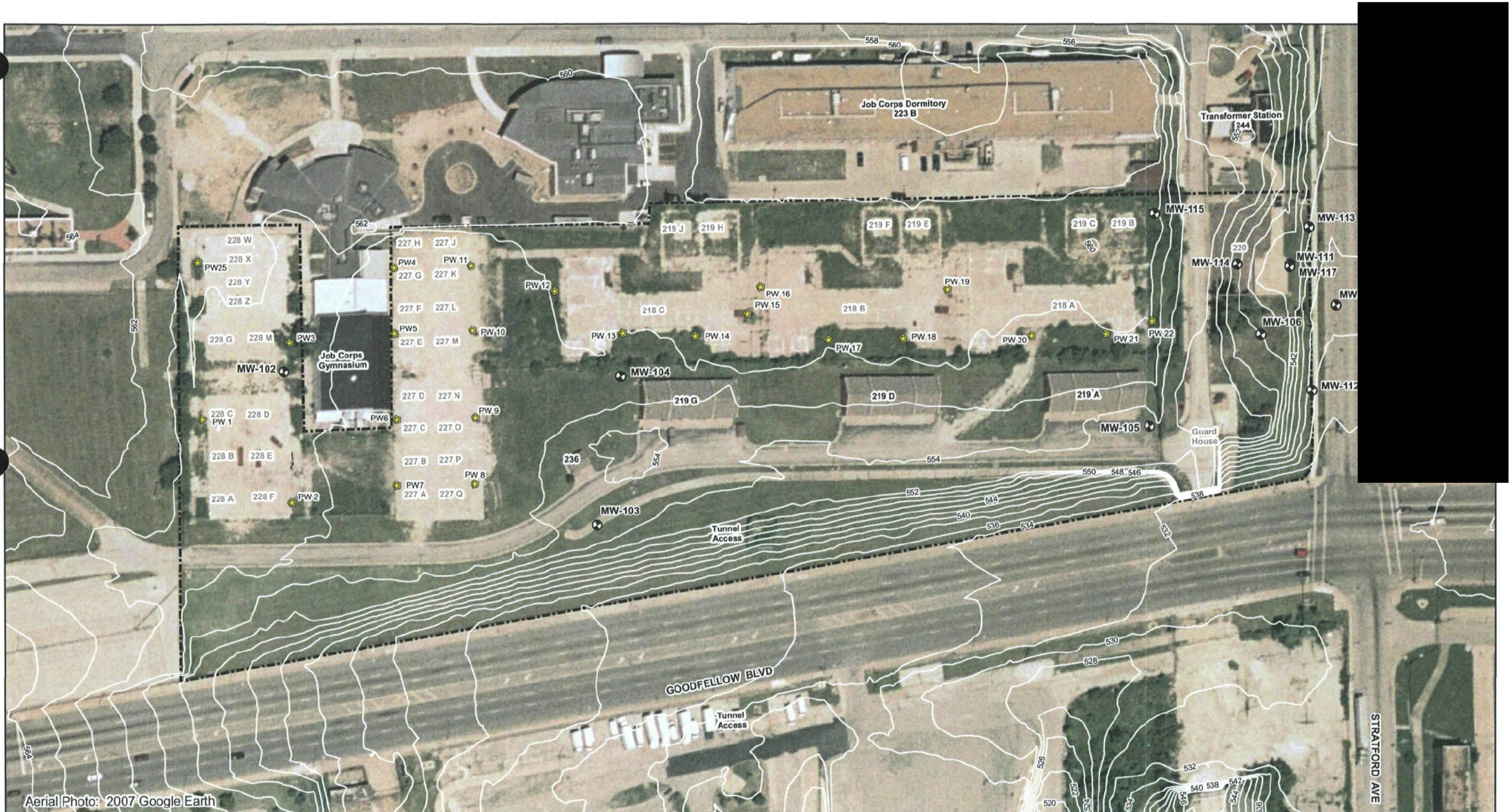
CH2MHILL



LEGEND

- Monitoring Well
- Powder Well
- Elevation Contour (2-foot interval)
- Site Boundary
- 220 Former Building

0 50 100 Feet

FIGURE 1-2
CURRENT SITE FEATURES
St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

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2. Conceptual Site Model

This section summarizes site characteristics regarding site geology, hydrogeology, nature, extent, fate, and transport of contamination, and chemicals of concern (COCs) identified by the risk assessment performed during the RI. COCs are chemicals that may pose risk to human health or the environment and are evaluated in the FS.

2.1 Soil and Bedrock Characteristics

Overburden soils at the site consist primarily of lean clay. The soil lithology is relatively consistent across the site. Fill material including gravel, concrete rubble, brick debris, and sand, were observed in portions of the site as deep as 11 feet. Figure 2-1 shows the location of the cross section depicted in Figure 2-2.

Lean clay was observed roughly 20 to 25 feet below ground (514.2 to 509.3 feet in elevation) in the north part of the former Hanley Area. Discontinuous lenses of silt were observed within the lean clay. A fat clay layer with discontinuous lenses of lean clay was observed to roughly 43 feet below ground at MW-115, decreasing in thickness to the north until pinching out near MW-108. The fat clay layer was observed at roughly 22 feet below ground at MW-117, 21 feet below ground at MW-107, 25 feet below ground at MW-108, and 25.5 feet below ground at MW-109. A hard, dry, completely weathered shale with discontinuous lenses of silt and clay underlies the clay.

The weathered shale is defined as considerably weakened rock that may behave as a soil but retains relict texture (Geological Society Working Group 1995). The discontinuous lenses of silt and clay within the weathered shale are likely the result of differential weathering along bedding planes, based on visual observations during the 2008 field investigation in the northern part of the former Hanley Area. The thickness of the weathered shale ranges from 6 to 12 feet in boreholes advanced to depths at which the competent bedrock was encountered (MW-116 and MW-117). Competent shale was encountered in well MW-116 at 34.0 feet below ground (500.3 feet in elevation) and in MW-117 at 38.3 feet below ground (503.1 feet in elevation). When the soil boring at MW-117 was advanced, a coal layer roughly 6 inches thick was observed at 45 feet below ground (496.4 feet in elevation).

2.2 Groundwater Characteristics

Groundwater is present within more permeable silt and clay lenses that are locally discontinuous within the upper clay (lean clay) unit.

Saturated conditions were not observed within the weathered shale underlying the clay unit. Groundwater was encountered in a 6-inch saturated coal layer within the competent shale zone. Groundwater within the coal does not appear to be hydraulically connected to groundwater observed in the discontinuous silt and clay lenses. In June 2008, the groundwater level measured in MW-117, screened within competent shale, was roughly

8.5 feet lower than the groundwater level measured in MW-111, located 4 feet west of MW-117 and screened in the overburden clay (Figure 2-2).

Groundwater generally flows from the south and west to the northeast. There is a local groundwater high west of former Building 220 in the northern part of the site. Figure 2-3 depicts the potentiometric surface there. The depth to groundwater within the overburden is 1 to 24 feet below ground. The depth to groundwater downgradient of Building 220 (near MW-111, MW-117, MW-110, MW-108, and MW-116) is less than 6 feet below ground. However, the depth to groundwater is more than 10 feet below ground upgradient of Building 220 (near CB-01 and CB-02). Groundwater was observed at roughly 33 feet below ground in CB-01 and 32 feet in CB-02. The potentiometric surface is fairly consistent across the site, sloping toward the northeast roughly parallel to the surface of the shale (Figure 2-2). The ground surface elevation within the site increases to the southwest of Stratford Avenue and again further southwest past the site road that parallels Stratford Avenue. The topographic changes appear to be related to construction at the site (grading and placement of fill), and the groundwater surface has no relationship to the site topography. Site documents reported that the underground tunnels 10 to 12 feet below ground in the elevated part of the site had very little water. The groundwater elevation onsite ranges from 528 to 542 feet.

During the 2008 field investigation, the groundwater within the temporary wells (e.g., CB-01 and CB-02) may not have had enough time to reach static levels. For example, the groundwater level at MW-115, located to the southwest and about 4 feet higher in elevation than CB-01 and CB-02, was observed at elevation 536 feet (roughly 21 feet below ground), whereas the groundwater level at CB-01 and CB-02 was observed at elevations of 519.40 and 519.60 feet (roughly 34 feet below ground at both locations).

Groundwater level measurements made during the 2008 field investigation indicate that the horizontal groundwater gradients range from 0.054 to 0.019 foot per foot in the northern part of the former Hanley Area and from 0.048 to 0.010 foot per foot in the southern part of the former Hanley Area. The gradients are consistent with those reported in the 2007 RI (USACE 2007). Based on a geotechnical analysis of site soils during the 2008 RI, the hydraulic conductivity in the lean and high plasticity clay is relatively low, ranging from 1×10^{-5} to 1×10^{-7} centimeters per second. Using an assumed porosity of 30 percent, the lowest and highest hydraulic gradients (0.019 and 0.054 foot per foot), and the lowest and highest measured hydraulic conductivities (2.3×10^{-7} and 3.1×10^{-5} centimeters per second), the calculated groundwater velocity ranges from 0.79 foot to 5.77 feet per year.

2.3 Nature and Extent of Contamination Summary

The nature and extent of contamination in soil and groundwater contamination was delineated during the site investigations, except along the western property boundary adjoining the Job Corps property. In that area, arsenic concentrations in surface soil could not be delineated to the west because the Job Corps denied access. As part of the nature and extent evaluation, chemicals detected in the samples were compared to conservative risk-based screening levels, which assume a lack of institutional controls that would prohibit exposure to site contaminants. Institutional controls are discussed later in this report.

2.3.1 Surface Soil

Surface soil contamination (0 to 2 feet below ground) across the former Hanley Area consists primarily of metals. Antimony, arsenic, chromium, copper, lead, thallium, selenium, and silver were detected at concentrations greater than the corresponding screening levels in surface soil (Figure 2-4). With the exception of arsenic at the property boundary, these metals were delineated during previous investigations.

Tetrachloroethene (PCE) and trichloroethene (TCE) concentrations also exceeded screening levels in the northern part of the former Hanley Area, downgradient from the former Building 220 in 2007. The polychlorinated biphenyl (PCB) Aroclor 1260 exceeded the screening level near the southern boundary of the former Hanley Area. Detections above the screening level are shown in Figure 2-4.

2.3.2 Subsurface Soil

Metals and volatile organic compounds (VOCs) were measured at concentrations above screening levels in subsurface soil (more than 2 feet below ground) beneath the former Hanley Area. The metals in the subsurface were determined to be naturally occurring, and so no further action is needed to address them. Subsurface VOC contamination in saturated soil is present around former Building 220 in the northern part of the site (Figure 2-5). VOC contaminant mass near former Building 220 is likely related to the migration of the constituents in groundwater and will be addressed with the groundwater. Dense nonaqueous phase liquid (DNAPL) was not observed during boring installation at MW-117 and groundwater sampling activities conducted at MW-111 and MW-117. However, PCE observed in soil at the 2007 soil boring SB-023 (3,200,000 µg/kg) at 25 to 26 feet below ground could indicate the presence of DNAPL above the weathered shale.

2.3.3 Groundwater

Dissolved-phase groundwater contamination exists in the northern part of the site, consisting of three distinct plumes comprising one or more of chlorinated VOCs (cVOCs). In addition, other VOCs were detected at concentrations above screening levels in isolated occurrences within and around the plumes (Figure 2-6).

2.3.3.1 Plume A

PCE, TCE, and *cis*-1,2-dichloroethene (*cis*-1,2-DCE) make up Plume A. The sewer system downgradient and northeast of former Building 220 is suspected to be the primary source of Plume A. The presence of TCE and *cis*-1,2-DCE may be attributed to reductive dechlorination of PCE. There is no historical record of a single large spill, but sporadic discharge of small quantities of spent product is assumed to have occurred. Figure 2-6 illustrates the extent of the PCE and TCE at concentrations above the USEPA Maximum Contaminant Level (MCL) of 5 micrograms per liter (µg/L) and *cis*-1,2-DCE above the MCL of 70 µg/L. The MCLs were used as the screening levels for contaminants in groundwater. The depth of contamination is just below ground to the weathered shale interface at roughly 26 to 28 feet below ground. During the RI, groundwater levels within Plume A ranged between 0.20 foot below ground at MW-110 to 4.76 feet below ground at MW-109.

2.3.3.2 Plume B

1,2-Dicholoroethane (1,2-DCA) makes up Plume B, which is largely commingled with Plume A. The source of Plume B is unknown, but it may be associated with leaks in the sewer collection system near confirmation boring CB-04. Figure 2-6 illustrates the extent of Plume B at concentrations above 5 μg/L, the MCL. The depth of contamination is just below ground to the weathered shale interface at roughly 24 to 30 feet below ground. During the RI, groundwater levels within Plume B ranged from 0.20 foot below ground at MW-110 to 10.31 feet below ground at MW-106.

2.3.3.3 Plume C

Plume C, southwest of former Building 220, consists of commingled carbon tetrachloride (CT), chloroform, and TCE. The source of Plume C is unknown. CT and TCE appear to be the original constituents of the plume, with chloroform present as a breakdown product of CT. The extent of the plume is small and has been delineated in the downgradient direction. Figure 2-6 illustrates the extent of the CT and TCE at concentrations above 5 μg/L, the MCL for drinking water. The depth of contamination is more than 10 feet below ground, which is the estimated depth of groundwater in this area, to the weathered shale interface at roughly 34 feet below ground. The depth to groundwater at Plume C is estimated based on the depth to groundwater at MW-115 (21.22 feet below ground) to the southwest and the depth to water at MW-114 (2.93 feet below ground). The ground surface elevation is 557.64 feet at MW-115 and 543.75 feet at MW-114. During RI confirmation groundwater sampling within the core of the CT plume at CB-01 (ground surface elevation of 553.37 feet), groundwater was encountered at 34.20 feet below ground. That well is temporary and may not represent the static depth to groundwater.

2.3.4 Vapor Intrusion

The potential for vapor intrusion was assessed by collecting indoor and ambient air samples on two occasions from the vacant residence at 6317 Stratford Avenue. No risk to residents was identified based on the measured concentrations of cVOCs in the indoor air samples.

2.3.5 Powder Well Sediment

The sediment within the powder wells, though characterized, was not evaluated in the human health risk assessment (HHRA) because it will be removed as part of a remedial action. The powder well locations are shown in Figure 1-2.

2.4 Contaminant Fate and Transport

This section summarizes the relevant physical and chemical properties of site contaminants, fate and transport processes, and the conceptual site model based on chemicals detected at concentrations above the risk-based screening levels. Additional details regarding contaminant fate and transport was provided in Section 6 of the RI Report (CH2M HILL 2009a).

2.4.1 Physical and Chemical Properties

Mobility and persistence are terms used to describe the movement and partitioning of chemicals in the environment. *Mobility* is the potential for a chemical to migrate through a medium; *persistence* is a measure of how long a constituent will remain in the environment. Several physicochemical properties typically are used to predict the mobility and persistence of contaminants in environmental media. Principal properties that influence mobility and persistence include water solubility, Henry's law constant, carbon/water partition coefficient (K_{oc}), distribution coefficient, and half-life. These properties are described in Table 2-1. Physical and chemical properties for the site COCs are described in Table 2-2.

2.4.2 Fate and Transport Processes

In addition to chemical and physical properties of contaminants, nondestructive and destructive processes in the environment affect the fate and transport of chemicals.

2.4.2.1 Nondestructive Processes

Nondestructive fate and transport mechanisms reduce contaminant concentrations but do not reduce the total contaminant mass. Nondestructive processes include advection, dispersion, diffusion, sorption, and volatilization. Advection is the transport process by which dissolved solutes in the saturated zone are transported by the bulk motion of groundwater flow. Hydrodynamic dispersion is responsible for the spreading of a solute plume that typically occurs with distance traveled. Diffusion involves the movement of solute in the direction of concentration gradients. Sorption occurs when a compound adheres to and becomes associated with solid particles in the formation. Volatilization is the conversion of a compound from the liquid or solid state into the gaseous state.

Metals in the solid or sorbed phases tend to remain immobile, unless some environmental change occurs that causes their transformation to a more water soluble form, as discussed below. PCBs, which have high K_{oc} values, are virtually immobile, unlike cVOCs which have lower K_{oc} values.

cVOCs such as CT and vinyl chloride are most likely to volatilize, followed by other chlorinated ethenes and methanes and benzene, and then the less volatile chlorinated ethanes and naphthalene. PCBs, multi-ringed PAHs, and metals (with rare exceptions) are essentially nonvolatile.

Metals undergo non-destructive processes through transformation reactions in response to changes in pH and redox potential (E_h). These reactions may be microbially mediated or abiotic. The most important transformations for contaminant fate and transport are metals oxidation/reduction and precipitation/dissolution reactions. Metals do not undergo destructive processes.

2.4.2.2 Destructive Processes

Destructive fate and transport mechanisms decrease the observed concentration and the mass of a chemical. cVOCs can be degraded by both biotic and abiotic destructive mechanisms. Biotic degradation, or biodegradation, is the process by which chemicals are decomposed by direct or indirect reactions with microorganisms, whereas abiotic degradation occurs without microorganisms. Organics often undergo both biotic and abiotic degradation. PCBs may persist for years in shallow soils and sediment because of their poor biodegradability.

2.4.3 Conceptual Site Model

2.4.3.1 Surface and Unsaturated Subsurface Soil

From a fate and transport perspective, PCBs and metals released to surface soil tend to be immobile and remain near their point of release. At the former Hanley Area, the distribution of these chemicals in soil suggests that they have not migrated far from their points of release. The site is relatively flat and well covered with grass or pavement, so migration by soil erosion or windblown dust does not appear to be a significant pathway. Leaching of these chemicals into groundwater does not appear to be of concern because of the low water solubility of the chemicals and the low metal concentrations observed in onsite groundwater

PCE and TCE are the cVOCs identified as COCs in surface and vadose zone soils at the former Hanley Area. PCE and TCE could have been released to the environment as dissolved-phase constituents in water or as free-phase product (DNAPL). Dissolved-phase PCE and TCE would migrate downward and be subject to soil sorption and volatilization. Likewise, free-phase PCE and TCE would migrate downward and be subject to soil sorption and volatilization, as well as dissolution into soil moisture and retention of discontinuous and immobile DNAPL droplets in soil pores often referred as residual DNAPL. Precipitation and infiltration will continue to leach sorbed phase PCE and TCE (and residual DNAPL, if any) downward to the saturated zone over time, constituting a continuing source of contaminants to groundwater.

At the former Hanley Area, volatilization may be an important fate mechanism for PCE and TCE in surface and vadose zone soil. However, it is difficult to quantify. Volatilization of PCE and TCE can occur from the aqueous phase, from the sorbed phase, or from vaporization of DNAPLs. Volatilization occurs at interfaces between phases (soil/gas, water/gas, DNAPL/gas) in the vadose zone and at the groundwater/gas interface at the top of the saturated zone. Consequently, volatilization is normally more important as a fate process for surface soil and vadose zone soil contamination. Volatilization of PCE and TCE would result in decreased concentrations of these VOCs in contaminated soil or groundwater.

Biodegradation of PCE and TCE may also be occurring in the vadose zone, but since the redox conditions are mostly aerobic/oxidizing, biodegradation is probably largely confined to compounds amenable to aerobic respiration. The degree to which this is occurring is difficult to evaluate or quantify. Biodegradation of PCE and TCE would result in decreased concentrations of these VOCs in contaminated soil or groundwater.

2.4.3.2 Saturated Soil and Groundwater

cVOCs are the principal groundwater contaminants in saturated soil and groundwater. Since PCE is denser than water, free-phase PCE reaching the water table would continue to migrate downward until reaching a relatively impermeable barrier. Direct evidence of DNAPL was not observed during the field investigations; but the concentrations found in soil and groundwater suggest the presence of DNAPL. DNAPL could be present at or above the weathered shale or overlying the competent shale bedrock surface. Sorbed-phase cVOCs in hotspot areas serve as a continuing source of contaminants to groundwater as they desorb to equilibrate with groundwater flowing through the source area. Dissolved-phase cVOCs are transported by advection and retarded by sorption (as described above) in the direction of groundwater flow.

The principal destructive fate mechanism for cVOCs is likely to be biodegradation. Biological reductive dechlorination is the principal cVOC biodegradation process in groundwater systems, and there is evidence of reductive dechlorination occurring at the site. The evidence is the presence of reductive dechlorination biotransformation products: (a) TCE, *cis*-1,2-DCE, and vinyl chloride, indicating reductive dechlorination of PCE in Plume A; and (b) chloroform, indicating reductive dechlorination of CT in Plume C. Geochemical parameter data do not provide much supporting evidence for reductive dechlorination at the site. It is not unusual to observe some breakdown product evidence of reductive dechlorination under these conditions, because anaerobic microsites can exist even when the bulk groundwater is aerobic; however, the extent of cVOC breakdown is usually limited at such sites.

Aerobic biodegradation of susceptible cVOC compounds (e.g., 1,2-DCA) might also be occurring, based on elevated dissolved oxygen and oxidation-reduction potential readings observed during the RI. 1,2-DCA and vinyl chloride, and in some cases *cis*-1,2-DCE are amenable to aerobic respiration. Aerobic biodegradation can be an important fate mechanism for these compounds when they are present in conjunction with elevated dissolved oxygen concentrations.

Certain cVOCs are potentially amenable to aerobic co-metabolism in which microbial utilization of a primary substrate induces production of nonspecific enzymes that fortuitously initiate transformation of the cVOC. Compounds saturated with chlorine (such as PCE and CT) and some other multichlorinated cVOCs cannot be biodegraded via aerobic co-metabolism. In any case, this process in unlikely to be an important fate mechanism at this site because it requires the simultaneous availability of a primary substrate and dissolved oxygen, as well as the appropriate microbial population.

2.4.4 Modeling

Plume A. REMChlor Version 1.0 was used to model the fate and transport of Plume A. The model was developed by Clemson University's Departments of Geological Sciences and Environmental Engineering and reviewed by USEPA and the Center for Subsurface Modeling Support. REMChlor was selected because of its ability to predict remediation effectiveness. Because of simplifying assumptions, specific results should be considered order-of-magnitude and useful for basic understanding of plume stability. Predicting absolute plume length dynamics over time is beyond the capability of the model given the amount of available data. The model input parameters were included in the RI.

The footprint or plume area of cVOC concentrations above the MCLs is less than one-half of an acre, which includes the area with concentrations of PCE, TCE, and *cis*-1,2-DCE in groundwater above the screening levels. The TCE plume is larger than the PCE plume, because TCE has a higher water solubility level. TCE is estimated to be 145 feet (or about 44 meters) from the original source area, the sanitary sewer line near MW-111. Because it is not known when the contaminants were released, the model was used to estimate possible release dates and to assess plume stability (i.e., whether the plume is stable, or increasing or decreasing in size). VOC concentrations measured in 2008 groundwater samples were used to calibrate the model.

Using the 2008 data and considering the known period of industrial operations at the site (1941 through 1979), the model estimates a possible date of release around 1959, or 49 years before the calibration year (2008) of the model. Assuming a 1959 release date, the 2008 plume length is consistent with an average migration velocity of 3 feet per year, which is within the groundwater velocity range. Note that contaminant migration velocity is typically slower than groundwater velocity because of retardation factors. The rate at which groundwater and contaminants move at the site is directly related to the soil and contaminant characteristics. At the former Hanley Area, groundwater and contaminants may move faster because of preferential pathways or more slowly because of the discontinuous lenses of more permeable soil. Also, as for the release date assumed as part of the modeling, it is possible and somewhat likely that several small releases have occurred throughout the operating period of the site, rather than a one-time release as assumed in the model discussion below.

Based on the REMChlor model predictions of a 1959 release, the leading edge of Plume A is either already near its maximum extent or will be within the next 5 years, if left untreated. The model suggests that the TCE plume may migrate toward Stratford Avenue for another 3 years (that is, until 2011) before the plume begins to shrink because of destructive or nondestructive fate and transport processes. At year 52, the TCE will have migrated about 45 meters (148 feet) from MW-111 (the assumed original source area used for modeling purposes).

There is uncertainty associated with the REMChlor model, such as the actual release date, number of releases, the amount of chlorinated solvent released, type of chlorinated solvents released (e.g., TCE, PCE), and amount of reduction occurring naturally at the site. To assess the uncertainty, a spill release date of 1941 and a release date of 1979 also were modeled. The 1941 release scenario indicates that the plume footprint may be decreasing. The 1979 scenario suggests that the plume will continue to migrate for 70 years after the calibration year of 2008 before it begins to shrink. At its maximum extent in 2078, the plume will have migrated 85 meters (279 feet), an additional 40 meters (131 feet) downgradient from the 2008 leading edge of the plume.

Plume B. The area in which 1,2-DCA concentrations exceed the screening levels is less than one-third of an acre. The leading edge of the 1,2-DCA plume extends about 130 feet from Building 220. 1,2-DCA generally is more mobile in groundwater because it has a higher solubility and lower K_{oc}. The original source area of 1,2-DCA is unknown.

Modeling was not conducted for the 1,2-DCA plume because a contaminant source was not evident based on available information. Assuming a conservative contaminant migration velocity (equal to the groundwater velocity) of 3 feet per year, the leading edge of Plume B where concentrations exceed screening levels would extend beyond the northern edge of Stratford Avenue in about 4 years (in 2012).

Plume C. The footprint of the CT plume is about one-fifth of an acre. As demonstrated by the presence of chloroform, limited CT reductive dechlorination may be occurring. The K_{oc} value for CT is similar to that for TCE; therefore, some migration is to be expected. *However, the small and isolated Plume C footprint, which is bounded by sampling* locations where CT was not detected, suggests that the CT is relatively immobile and may be entrapped within fine-grained subsurface materials. Another possible explanation for the limited extent of CT is that it was released more recently than the contaminants observed in Plumes A and B. CT is commingled with TCE in Plume C. The TCE does not appear to have degraded anaerobically, as indicated by the lack of daughter products, such as *cis*-1,2-DCE.

2.5 Human Health Risk Assessment Summary

An HHRA was performed to evaluate potential current and future risks associated with constituents detected at the site in the surface soil, subsurface soil, groundwater, and indoor air data. HHRA methods and findings are summarized in the RI report (CH2M HILL 2009a).

2.5.1 Soil

During a teleconference on September 2, 2008, representatives from MDNR, Missouri Department of Health and Senior Services (MDHSS), USEPA, and USACE agreed that certain areas of soil with elevated arsenic and lead concentrations would be removed and therefore excluded from the HHRA. Those areas will be addressed through a soil removal action during remedy implementation. The surface soil samples and chemicals identified for removal are:

- Sample NS03A arsenic at 44 milligrams per kilogram (mg/kg); lead at 5,840 mg/kg
- Sample NS08A arsenic at 67.7 mg/kg
- Sample SS-218A-2 lead at 2,724 mg/kg
- Sample SS-219B arsenic at 108 mg/kg
- Sample SS-219C arsenic at 68.8 mg/kg

As with arsenic and lead, PCBs were excluded from the HHRA because the upcoming soil removal action will address the concentrations below.

- Sample SS-001 Aroclor 1260 at 1.44 mg/kg
- Sample SED-001 Aroclor 1260 at 569 mg/kg
- Sample SS55A Aroclor 1260 at 18,200 mg/kg

The HHRA calculated risk estimates for current industrial workers to surface soil (0 to 2 feet below ground) and for future construction worker exposure to subsurface soil (0 to 10 feet below ground). No unacceptable risks associated with these exposure pathways were found.

While the site is identified by the St. Louis City Zoning Department as industrial, commercial, and residential, the HHRA evaluated residential exposure to onsite subsurface soil. To evaluate residential exposure to onsite subsurface soil, the HHRA calculated risk estimates for 12 hypothetical exposure units, roughly the size of a 1-acre residential lot, to address concerns regarding concentration dilution. Figure 2-7 depicts the exposure units. For HHRA purposes, soil from the 0-to-10-foot depth range was evaluated for potential residential exposure, since in the future, soil greater than 2 feet in depth could be brought to the surface during future redevelopment.

The HHRA identified several COCs for potential residential exposure to subsurface soil. COCs are chemicals that yield an individual excess lifetime cancer risk greater than 1×10^{-5}

or an individual hazard index (HI) greater than 0.1 contributing to a target organ HI greater than 1.0.

The following subsurface soil COCs (Figure 2-7) were identified in the HHRA:

- Onsite Subsurface Soil (Residents):
  - Exposure Unit E—Antimony and thallium
  - Exposure Unit I—Thallium
  - Exposure Unit J—Thallium
  - Exposure Unit K—Thallium

2.5.2 Groundwater

The HHRA calculated risks estimates to residents, construction workers, and industrial workers exposed to onsite and offsite groundwater. Groundwater at the site is not used for potable purposes, and offsite residents do not use groundwater as a potable water supply. St. Louis City Ordinance 66777 prohibits the installation of potable water supply wells. Hypothetical potable use of groundwater (all available depths) was evaluated in the HHRA at the request of MDNR and MDHSS, even though the current and future exposure pathways are incomplete because of the City Ordinance. The following groundwater COCs were identified:

- Onsite Groundwater
  - Tapwater (Resident)—benzene, CT, chloroform, 1,2-DCA, *cis*-1,2-DCE, *trans*-1,2-dichloroethene (*trans*-1,2-DCE), manganese, naphthalene, 1,1,1,2-tetrachloroethane (1,1,1,2-TeCA), 1,1,2,2-tetrachloroethane (1,1,2,2-TeCA), 1,1,2-trichloroethane (1,1,2-TCA), PCE, and TCE.
  - Groundwater in Excavation (Construction Worker)—CT (part of Plume C) and PCE (part of Plume A)
- Offsite Groundwater
  - Tapwater (Resident) — Chloroform, 1,2-DCA, manganese, PCE and TCE; the risk estimates for this scenario are driven by the elevated concentrations detected in MW-110, situated in the middle of Stratford Avenue

The HHRA estimated risks to construction workers by assuming that that onsite and offsite groundwater lies within 10 feet below ground, the maximum depth at which the groundwater direct contact pathway for construction workers is considered complete. This assumption overestimates construction worker risk associated with CT in Plume C, where groundwater was estimated to be more than 10 feet below ground. This information was considered during the development of remedial alternatives for the FS.

VOCs are present in site groundwater in an area downgradient of former Building 220. There is a potential pathway for vapor intrusion into current and future onsite residences from shallow groundwater. Because the groundwater in that part of the site is very shallow (ranging from less than 1 foot to 5 feet below ground), potential indoor air concentrations resulting from vapor intrusion cannot be modeled using the Johnson & Ettinger Model. Future indoor air exposures within buildings constructed in the area may be at unacceptable levels because of high concentrations detected and shallow groundwater depths.

2.5.3 Powder Well Sediment

In 2001, 22 powder wells were located across the former Hanley Area. Eighteen of the powder wells contain sediment with various metal concentrations that exceed screening levels. Explosives in powder well samples were not detected at concentrations above screening levels. As part of the remedial action at the former Hanley Area, the 22 powder wells will be decommissioned. The sediment will be removed and disposed of based on characterization sampling, and the wells will be filled with clean, imported soil to ground surface. Because the powder well sediment will be addressed through a removal action, risk associated with powder well sediment was not evaluated in the RI report.

2.6 Ecological Risk Assessment Summary

Potential risks to terrestrial plants and soil invertebrates are indicated for direct exposure to chromium, lead, manganese, selenium, thallium, vanadium, and zinc. When interpreting the results for chromium and vanadium, it is important to note that the screening value for chromium is very conservative, and that the screening value for vanadium is based on other exposure routes. Ecological soil screening levels (Eco-SSLs) for terrestrial plants and soil invertebrates could not be derived for chromium and vanadium because too few studies have been conducted, but the effect levels listed in the Eco-SSL studies were much higher than the screening values used in the ecological risk assessment and generally higher than the average concentrations at the site. Although site-specific background data are unavailable, the 50th percentile background levels reported in the Eco-SSLs for chromium and vanadium and the eastern U.S. are very similar to the average concentrations at the site.

Selenium concentrations exceeded the Eco-SSL for plants, but selenium is not expected to pose risk to terrestrial plants because the Eco-SSL was only slightly exceeded. The Eco-SSL is based primarily on toxicity to agricultural crops, which are more sensitive to selenium than other terrestrial plants. Furthermore, the soils at the site are expected to be slightly acidic and less oxidized, and bioavailable forms of selenium are expected to be present. As with chromium and vanadium, selenium levels at the site appear similar to the background levels in the eastern U.S. Average concentrations of lead, manganese, and zinc exceeded Eco-SSLs only slightly.

Available habitat is limited to enclosed and maintained grassy areas. Although plant and invertebrate receptors are present at the site, the habitat does not represent a natural ecosystem, as it is controlled by human activity. The potential for adverse effects to terrestrial plants and soil invertebrates exists, but the nature of the habitat in the regularly disturbed area is likely to limit the diversity and abundance of terrestrial plants and soil invertebrates and the overall potential for adverse effects to receptor communities. These conditions suggest that risks are negligible, and no further investigation is warranted.

TABLE 2-1
Physical / Chemical and Environmental Fate Parameters
St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Parameter	Definition
Water solubility	Water solubility is the maximum mass of a compound that can dissolve in a specific volume of water at a specific pH and temperature. Highly soluble compounds tend to be more mobile in groundwater, tend to leach from the soils, and are generally more biodegradable. The lower the solubility, the more likely the compound is to adsorb to soil or sediment. Aqueous concentrations in excess of the solubility may indicate sorption onto sediment, the presence of solubilizing chemicals such as solvents, or the presence of a NAPL.
Henry's law constant	Henry's law constant describes the distribution of a chemical between air and water at equilibrium. It is usually defined as the ratio of the spatial pressure of the compound in air, measured in atmospheres, to the mole fraction of the compound in a water solution. A high Henry's law constant indicates a tendency for a compound to volatilize rather than remain in water.
K_{oc}	The soil organic carbon/water partitioning coefficient, K_{oc}, is indicative of a compound's water solubility and the sorptive capacity of the compound onto organic material at equilibrium. The higher the K_{oc}, the more likely a chemical is to bind to soil or sediment than to remain in water.
K_d	The distribution coefficient, K_d, is a soil- or sediment-specific measure of the extent of chemical partitioning between the soil or sediment and the water. The extent of sorption can be reasonably calculated if the organic carbon content in the soil (f_{oc}) is known by using $K_d = K_{oc} \times f_{oc}$. The higher the K_d, the more likely a chemical is to bind to soil or sediment than to remain in water.
Biodegradation half-life	Biodegradation is the biological decomposition or chemical alteration of organic compound by microorganisms. Abiotic degradation such as photolysis can also decompose organic compounds.

TABLE 2-2
Site-Specific COC Physical / Chemical Properties
St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Chemical	Literature Solubility[a] (mg/L)	K_{oc}[a] (mL/g)	Henry's Law Constant[a] (H, atm-m^3/mol)
Benzene	1,780[b]	79[b]	0.00543[b]
CT	825	439	0.0298
Chloroform	8,000	44	0.00358
1,2-DCA	8,500	14	0.0015
cis-1,2-DCE	3,500	86	0.00374
trans-1,2-DCE	6,300	59	0.00916
1,1,2,2,-TeCA	2,900	118	0.000459
1,1,2-TCA	4,400	56	0.00108
PCE	200	364	0.0174
TCE	1,100	126	0.00937

[a] James F. Pankow and John A. Cherry. 1996. *Dense Chlorinated solvents and Other DNAPLs in Groundwater: History, Behavior, and Remediation.*

[b] U.S. Environmental Protection Agency. 1990. *Subsurface Contamination Reference Guide.* EPA/540/2-90/11. Washington, D.C. 13 pp.

[redacted]

LEGEND

- Soil Boring
- Confirmation Boring
- Monitoring Well
- Cross Section
- Site Boundary
- 220 Former Building

Approximate Utilities

- Natural Gas
- Sanitary Sewer
- Telephone
- Water

N

0 30 60 Feet

FIGURE 2-1
LOCATION OF CROSS-SECTION A-A'
St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

STL \\LACLEDE\PROJ\CONTIENVIRONMENT\364298FLWSLOP00_PROPOSAL\FLW&SLOPS\SLOP_GIS\FILES_FROM_MIKE\MAPFILES\FS\FIG_2-1_CROSSECTION_A_A.MXD RHURSEY 8/7/2009 13:45:00

CH2MHILL

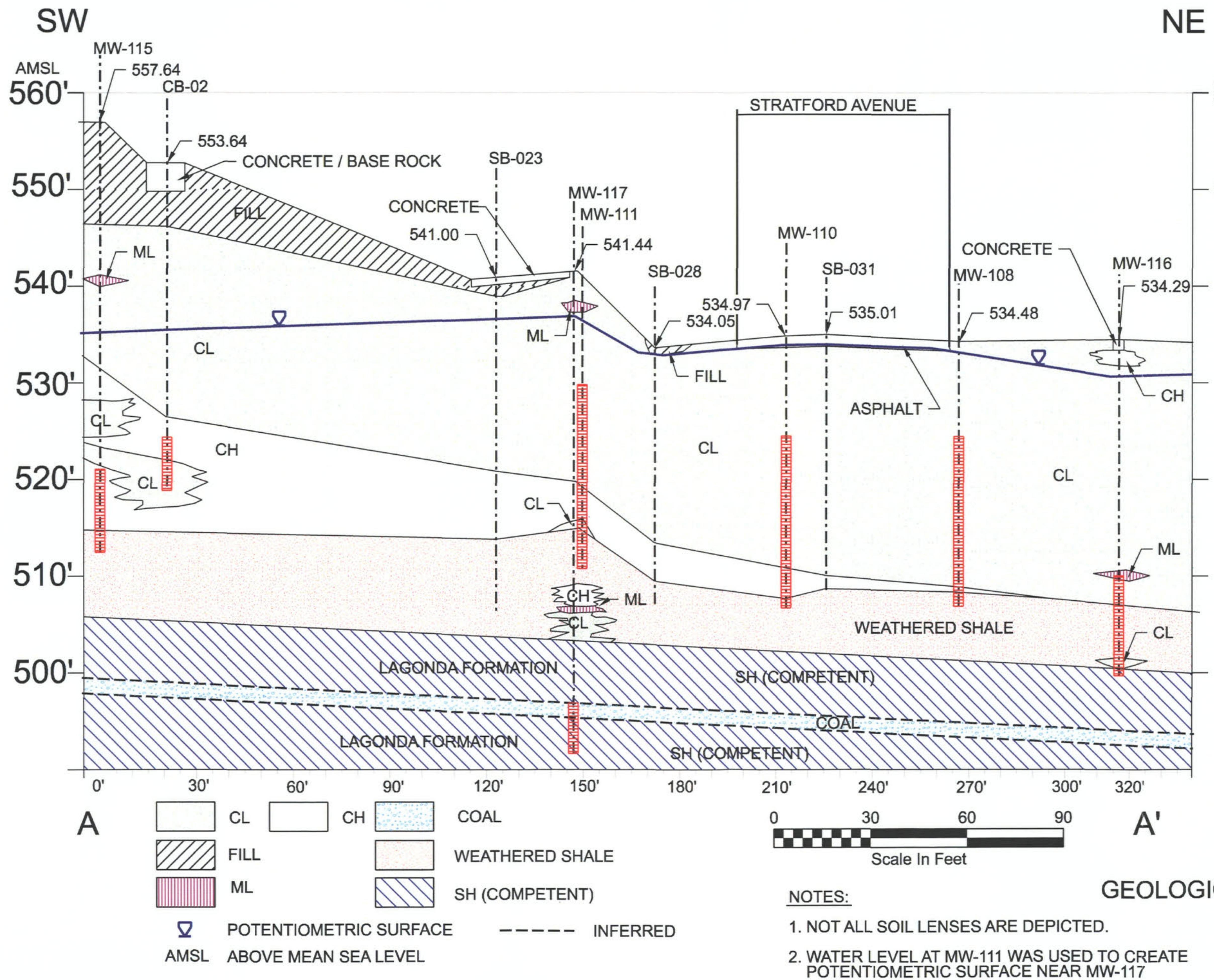


FIGURE 2-2
GEOLOGIC CROSS SECTION A-A'

St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

LEGEND

- Monitoring Well with Groundwater Elevation
- Groundwater Flow Direction
- Potentiometric Surface Contour
- 220 Former Building
- Site Boundary

Approximate Utilities
- Natural Gas
- Sanitary Sewer
- Telephone
- Water

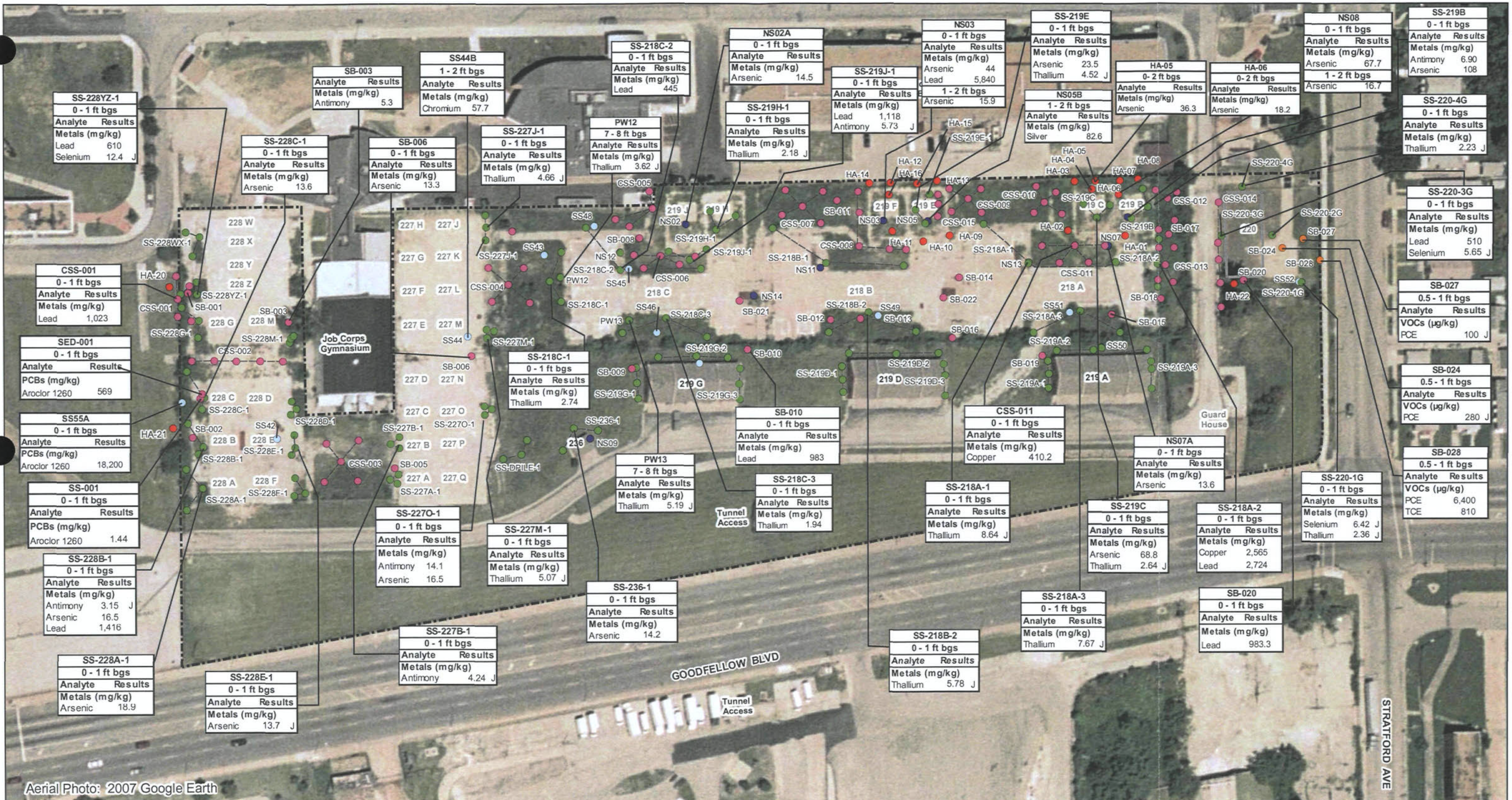
0 30 60 Feet

NOTE:
Water level measurements were collected on June 2, 2008.

FIGURE 2-3
POTENTIOMETRIC SURFACE MAP
St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

CH2MHILL

STL \\LACLEDE\PROJ\CONT\ENVIRONMENT\364298FLWSLOP\00_PROPOSAL\FLW&SLOPS\SLOP_GIS\FILES_FROM_MIKE\MAPFILES\FS\FIG_2-3_POT_SURF.MXD RHURSEY 8/7/2009 13:43:09



LEGEND

- 2008 Soil Sample
- 2007 Soil Sample
- 2005 Soil Sample
- 2001 Soil Sample
- 1998 Soil Sample Locations
- 1991 Soil Sample
- Composite Sample Portion Line
- Site Boundary
- 220 Former Building

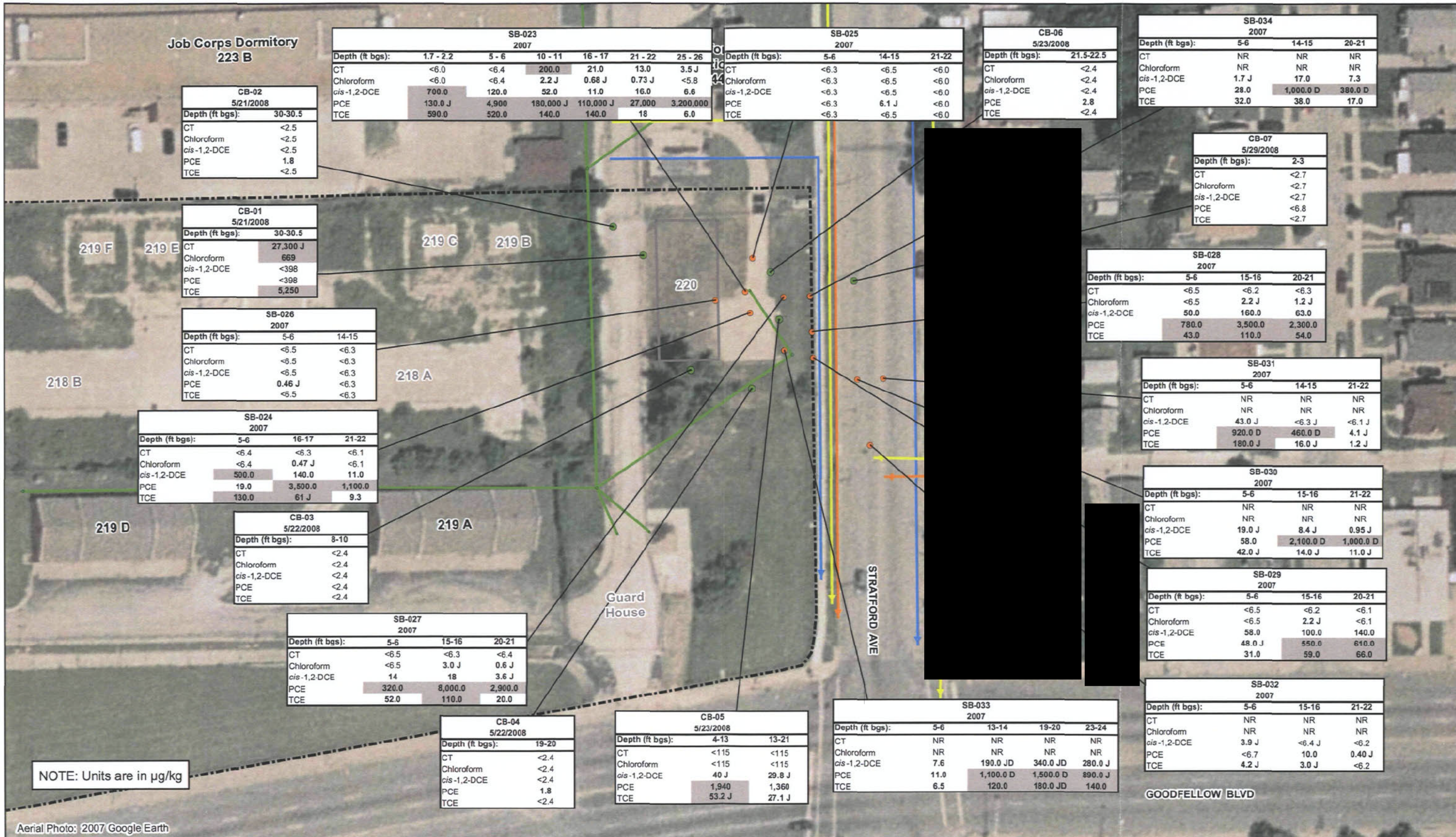
0 50 100 Feet

NOTE:
1. J = Reported value is estimated.
2. PCB = Polychlorinated biphenyl
3. VOC = Volatile Organic Compound
4. mg/kg = milligram per kilogram
5. µg/kg = microgram per kilogram
6. PCE = Tetrachloroethene
7. TCE = Trichloroethene

FIGURE 2-4
VOCs, METALS, AND PCBs IN SURFACE SOIL AT CONCENTRATIONS EXCEEDING SCREENING LEVELS
St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

CH2MHILL

\\LACLEDE\PROJ\CONTIENVIRONMENT\364298FLWSLOP\00_PROPOSAL\FLW&SLOPS\SLOP_GIS\FILES_FROM_MIKE\MAPFILES\FS\FIG_2-4_SURFACE_SOIL_METALS_PCBS_EXCEEDS.MXD RHURSEY 1/11/2010 09:42:00



SB-023 2007

Depth (ft bgs):	1.7 - 2.2	5 - 6	10 - 11	16 - 17	21 - 22	25 - 26
CT	<6.0	<6.4	200.0	21.0	13.0	3.5 J
Chloroform	<6.0	<6.4	2.2 J	0.68 J	0.73 J	<5.8
cis-1,2-DCE	700.0	120.0	52.0	11.0	16.0	6.6
PCE	130.0 J	4,900	180,000 J	110,000 J	27,000	3,200,000
TCE	590.0	520.0	140.0	140.0	18	6.0

SB-025 2007

Depth (ft bgs):	5-6	14-15	21-22
CT	<6.3	<6.5	<6.0
Chloroform	<6.3	<6.5	<6.0
cis-1,2-DCE	<6.3	<6.5	<6.0
PCE	<6.3	6.1 J	<6.0
TCE	<6.3	<6.5	<6.0

CB-06 5/23/2008

Depth (ft bgs):	21.5-22.5
CT	<2.4
Chloroform	<2.4
cis-1,2-DCE	<2.4
PCE	2.8
TCE	<2.4

SB-034 2007

Depth (ft bgs):	5-6	14-15	20-21
CT	NR	NR	NR
Chloroform	NR	NR	NR
cis-1,2-DCE	1.7 J	17.0	7.3
PCE	28.0	1,000.0 D	380.0 D
TCE	32.0	38.0	17.0

CB-02 5/21/2008

Depth (ft bgs):	30-30.5
CT	<2.5
Chloroform	<2.5
cis-1,2-DCE	<2.5
PCE	1.8
TCE	<2.5

CB-07 5/29/2008

Depth (ft bgs):	2-3
CT	<2.7
Chloroform	<2.7
cis-1,2-DCE	<2.7
PCE	<6.8
TCE	<2.7

CB-01 5/21/2008

Depth (ft bgs):	30-30.5
CT	27,300 J
Chloroform	669
cis-1,2-DCE	<398
PCE	<398
TCE	5,250

SB-028 2007

Depth (ft bgs):	5-6	15-16	20-21
CT	<6.5	<6.2	<6.3
Chloroform	<6.5	2.2 J	1.2 J
cis-1,2-DCE	50.0	160.0	63.0
PCE	780.0	3,500.0	2,300.0
TCE	43.0	110.0	54.0

SB-026 2007

Depth (ft bgs):	5-6	14-15
CT	<6.5	<6.3
Chloroform	<6.5	<6.3
cis-1,2-DCE	<6.5	<6.3
PCE	0.46 J	<6.3
TCE	<6.5	<6.3

SB-031 2007

Depth (ft bgs):	5-6	14-15	21-22
CT	NR	NR	NR
Chloroform	NR	NR	NR
cis-1,2-DCE	43.0 J	<6.3 J	<6.1 J
PCE	920.0 D	460.0 D	4.1 J
TCE	180.0 J	16.0 J	1.2 J

SB-024 2007

Depth (ft bgs):	5-6	16-17	21-22
CT	<6.4	<6.3	<6.1
Chloroform	<6.4	0.47 J	<6.1
cis-1,2-DCE	500.0	140.0	11.0
PCE	19.0	3,500.0	1,100.0
TCE	130.0	61 J	9.3

SB-030 2007

Depth (ft bgs):	5-6	15-16	21-22
CT	NR	NR	NR
Chloroform	NR	NR	NR
cis-1,2-DCE	19.0 J	8.4 J	0.95 J
PCE	58.0	2,100.0 D	1,000.0 D
TCE	42.0 J	14.0 J	11.0 J

CB-03 5/22/2008

Depth (ft bgs):	8-10
CT	<2.4
Chloroform	<2.4
cis-1,2-DCE	<2.4
PCE	<2.4
TCE	<2.4

SB-029 2007

Depth (ft bgs):	5-6	15-16	20-21
CT	<6.5	<6.2	<6.1
Chloroform	<6.5	2.2 J	<6.1
cis-1,2-DCE	58.0	100.0	140.0
PCE	48.0 J	550.0	610.0
TCE	31.0	59.0	66.0

SB-027 2007

Depth (ft bgs):	5-6	15-16	20-21
CT	<6.5	<6.3	<6.4
Chloroform	<6.5	3.0 J	0.6 J
cis-1,2-DCE	14	18	3.6 J
PCE	320.0	8,000.0	2,900.0
TCE	52.0	110.0	20.0

SB-032 2007

Depth (ft bgs):	5-6	15-16	21-22
CT	NR	NR	NR
Chloroform	NR	NR	NR
cis-1,2-DCE	3.9 J	<6.4 J	<6.2
PCE	<6.7	10.0	0.40 J
TCE	4.2 J	3.0 J	<6.2

SB-033 2007

Depth (ft bgs):	5-6	13-14	19-20	23-24
CT	NR	NR	NR	NR
Chloroform	NR	NR	NR	NR
cis-1,2-DCE	7.6	190.0 JD	340.0 JD	280.0 J
PCE	11.0	1,100.0 D	1,500.0 D	890.0 J
TCE	6.5	120.0	180.0 JD	140.0

CB-04 5/22/2008

Depth (ft bgs):	19-20
CT	<2.4
Chloroform	<2.4
cis-1,2-DCE	<2.4
PCE	1.8
TCE	<2.4

CB-05 5/23/2008

Depth (ft bgs):	4-13	13-21
CT	<115	<115
Chloroform	<115	<115
cis-1,2-DCE	40 J	29.8 J
PCE	1,940	1,360
TCE	53.2 J	27.1 J

LEGEND

- 2008 Confirmation Boring
- 2007 Soil Boring
- Site Boundary
- 220 Former Building

Approximate Utilities

- Natural Gas
- Sanitary Sewer
- Telephone
- Water

0 30 60 Feet

NOTES:

1. CT = carbon tetrachloride
2. cis-1,2-DCE = cis-1,2-dichloroethene
3. PCE = tetrachloroethene
4. TCE = trichloroethene
5. D = Qualified at dilution
6. VOC = volatile organic compound
7. J = Estimated Concentration
8. NR = Not reported
9. < = Chemical not detected above the method detection limit
10. Bold type indicates the chemical was detected
11. Shading indicates a detected concentration above the screening level.
12. ft bgs = feet below ground surface

FIGURE 2-5
VOCs IN SUBSURFACE SOIL AT CONCENTRATIONS EXCEEDING SCREENING LEVELS
St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

CH2MHILL

CB-02	
Screened Interval 30 - 35 ft bgs	
Chemical	Result (ug/L)
	5/22/2008
1,1,1,2-TeCA	<1
1,1,2,2-TeCA	<1
1,1,2-TCA	<1
1,2-DCA	<1
Benzene	<1
Carbon Tetrachloride	<1
Chloroform	<1
cis-1,2-DCE	<1
Naphthalene	<1
PCE	<1
trans-1,2-DCE	<1
TCE	<1
Vinyl Chloride	<1

CB-01	
Screened Interval 30 - 35 ft bgs	
Chemical	Result (ug/L)
	522/2008
1,1,1,2-TeCA	<5
1,1,2,2-TeCA	<5
1,1,2-TCA	**2.3 J**
1,2-DCA	<5
Benzene	**4 J**
Carbon Tetrachloride	**4,160 J**
Choroform	**790**
cis-1,2-DCE	<5
Naphthalene	**10.1**
PCE	<5
trans-1,2-DCE	<5
TCE	**1,040**
Vinyl Chloride	<5

MW-117	
Screened Interval 49 - 54 ft bgs	
Chemical	Result (ug/L)
	6/12/2008
1,1,1,2-TeCA	<1
1,1,2,2-TeCA	<1
1,1,2-TCA	<1
1,2-DCA	<1
Benzene	<1
Carbon Tetrachloride	<1
Chloroform	<1
cis-1,2-DCE	<1
Naphthalene	<1 J
PCE	<1
trans-1,2-DCE	<1
TCE	<1
Vinyl Chloride	<1

MW-113		
Screened Interval 10 - 27 ft bgs		
Chemical	Result (ug/L)	Result (ug/L)
	Apr-07	6/4/2008
1,1,1,2-TeCA	<5	<1
1,1,2,2-TeCA	<5	<1
1,1,2-TCA	NA	<1
1,2-DCA	<5	<1
Benzene	<5	<1
Carbon Tetrachloride	<5	<1
Chloroform	<5	<1
cis-1,2-DCE	<5	<1
Naphthalene	NA	<1
PCE	<5	**0.88 J**
trans-1,2-DCE	<5	<1
TCE	<5	<1
Vinyl Chloride	<5	<1

CB-06	
Screened Interval 20.5 - 25.5 ft bgs	
Chemical	Result (ug/L)
	5/23/2008
1,1,1,2-TeCA	<1
1,1,2,2-TeCA	<1
1,1,2-TCA	<1
1,2-DCA	<1
Benzene	<1
Carbon Tetrachloride	<1
Chloroform	<1
cis-1,2-DCE	<1
Naphthalene	<1
PCE	**5**
trans-1,2-DCE	<1
TCE	**0.41 J**
Vinyl Chloride	<1

MW-115	
Screened Interval 9 - 29 ft bgs	
Chemical	Result (ug/L)
	6/5/2008
1,1,1,2-TeCA	<1 J
1,1,2,2-TeCA	<1
1,1,2-TCA	<1 J
1,2-DCA	<1
Benzene	<1 J
Carbon Tetrachloride	**0.38 J**
Chloroform	<1
cis-1,2-DCE	<1
Naphthalene	<1 J
PCE	<1
trans-1,2-DCE	<1
TCE	<1
Vinyl Chloride	<1

MW-114		
Screened Interval 9 - 29 ft bgs		
Chemical	Result (ug/L)	Result (ug/L)
	Apr-07	6/3/2008
1,1,1,2-TeCA	<5	<1
1,1,2,2-TeCA	<5	<1
1,1,2-TCA	NA	<1
1,2-DCA	**3.3 J**	<1
Benzene	<5	<1
Carbon Tetrachloride	<5	<1
Chloroform	<5	<1
cis-1,2-DCE	<5	<1
Naphthalene	NA	<1
PCE	<5	**0.64 J**
trans-1,2-DCE	<5	<1
TCE	<5	**0.54 J**
Vinyl Chloride	<5	<1

MW-110		
Screened Interval 10 - 28 ft bgs		
Chemical	Result (ug/L)	Result (ug/L)
	Apr-07	6/5/2008
1,1,1,2-TeCA	<5	<20 J
1,1,2,2-TeCA	<5	<20
1,1,2-TCA	NA	<20 J
1,2-DCA	**150**	**100 J**
Benzene	<5	<20 J
Carbon Tetrachloride	<5	<20
Chloroform	**0.35 J**	<20
cis-1,2-DCE	**46**	**82.2 J**
Naphthalene	NA	<20 J
PCE	**7,700**	**9,440**
trans-1,2-DCE	**0.93 J**	<20
TCE	**82**	**129**
Vinyl Chloride	<5	<20

MW-111		
Screened Interval 10 - 30 ft bgs		
Chemical	Result (ug/L)	Result (ug/L)
	Apr-07	6/6/2008
1,1,1,2-TeCA	**16**	<50
1,1,2,2-TeCA	**0.58 J**	<50
1,1,2-TCA	NA	<50
1,2-DCA	<5	<50
Benzene	**0.22 J**	<50
Carbon Tetrachloride	**2.7 J**	<50
Chloroform	**20**	**23.8 J**
cis-1,2-DCE	**250 J**	**281**
Naphthalene	NA	<50
PCE	**29,000**	**34,900**
trans-1,2-DCE	**12**	<50
TCE	**1,400**	**1,620**
Vinyl Chloride	**0.32 J**	<50

CB-04	
Screened Interval 27.5 - 32.5 ft bgs	
Chemical	Result (ug/L)
	5/23/2008
1,1,1,2-TeCA	<1
1,1,2,2-TeCA	<1
1,1,2-TCA	<1
1,2-DCA	**189 J**
Benzene	<1
Carbon Tetrachloride	<1
Chloroform	<1
cis-1,2-DCE	<1
Naphthalene	<1
PCE	<1
trans-1,2-DCE	<1
TCE	<1
Vinyl Chloride	<1

MW-108		
Screened Interval 10 - 27 ft bgs		
Chemical	Result (ug/L)	Result (ug/L)
	Apr-07	6/4/2008
1,1,1,2-TeCA	<5	<1
1,1,2,2-TeCA	<5	<1
1,1,2-TCA	NA	<1
1,2-DCA	<5	<1
Benzene	<5	<1
Carbon Tetrachloride	<5	<1
Chloroform	<5	<1
cis-1,2-DCE	**10**	**9.4**
Naphthalene	NA	<1
PCE	<5	<1
trans-1,2-DCE	**0.54 J**	**0.6**
TCE	**18**	**16.8**
Vinyl Chloride	<5	<1

MW-106		
Screened Interval 15 - 35 ft bgs		
Chemical	Result (ug/L)	Result (ug/L)
	Apr-07	6/3/2008
1,1,1,2-TeCA	<5	<1
1,1,2,2-TeCA	<5	<1
1,1,2-TCA	NA	<1
1,2-DCA	**4.4 J**	**3.3**
Benzene	<5	<1
Carbon Tetrachloride	<5	<1
Chloroform	<5	<1
cis-1,2-DCE	<5	<1
Naphthalene	NA	<1
PCE	<5	<1
trans-1,2-DCE	<5	<1
TCE	<5	<1
Vinyl Chloride	<5	<1

MW-112		
Screened Interval 10 - 28 ft bgs		
Chemical	Result (ug/L)	Result (ug/L)
	Apr-07	6/5/2008
1,1,1,2-TeCA	<5	<1 J
1,1,2,2-TeCA	<5	<1
1,1,2-TCA	NA	<1 J
1,2-DCA	<5	<1 J
Benzene	<5	<1 J
Carbon Tetrachloride	<5	<1 J
Chloroform	<5	<1
cis-1,2-DCE	<5	<1 J
Naphthalene	NA	<1 J
PCE	<5	<1
trans-1,2-DCE	<5	<1 J
TCE	<5	<1
Vinyl Chloride	<5	<1

Analyte	MCL
VOCs (ug/L)	
1,1,1,2-TeCA	-
1,1,2,2-TeCA	-
1,1,2-TCA	5
1,2-DCA	5
Benzene	5
Carbon Tetrachloride	5
Chloroform	5
cis-1,2-DCE	-
Naphthalene	70
PCE	-
trans-1,2-DCE	100
TCE	5
Vinyl Chloride	2

N

0 30 60 Feet

LEGEND

- Groundwater Sample Point
- Temporary Well
- Monitoring Well
- Site Boundary
- 220 Former Building

Approximate Utilities
- Natural Gas
- Sanitary Sewer
- Telephone
- Water

- Area Exceeding MCL for 1,2-DCA (Plume B)
- Area Exceeding MCL for Carbon Tetrachloride (Plume C)
- Area Exceeding MCL for PCE, TCE, and cis-1,2-DCE (Plume A)

NOTES:
1. VOC = volatile organic compound
2. TeCA = tetrachloroethane
3. TCA = trichloroethane
4. DCA = dichloroethane
5. DCE = dichloroethene
6. PCE = tetrachloroethene
7. MCL = Maximum Contaminant Level
8. TCE = trichloroethene
9. J = Estimated Concentration
10. < = Chemical not detected above the method detection limit
11. Bold type indicates the chemical was detected
12. Shading indicates a detected concentration above the MCL.

FIGURE 2-6
2007 AND 2008 VOCs IN GROUNDWATER AT CONCENTRATIONS EXCEEDING MCLs
St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

CH2MHILL

LEGEND

Site Boundary

220 Former Building

Exposure Unit

Non-Exposure Unit

N

0 50 100 Feet

FIGURE 2-7
SOIL EXPOSURE UNITS
St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

STL \\LACLEDE\PROJ\CONTIENVIRONMENT\364298FLWSLOP\00_PROPOSAL\FLW&SLOPS\SLOP_GIS\FILES_FROM_MIKE\MAPFILES\FS\FIG_2-7_SUBSURF_SOIL_EXPOSURE_UNITS.MXD RHURSEY 10/8/2009 12:03:47

CH2MHILL

3. Alternative Development and Evaluation

The following steps were taken to develop and evaluate remedial alternatives for the former Hanley Area:

1. Identify ARARs.
2. Develop RAOs.
3. Determine PRGs and areas where they are exceeded.
4. Evaluate COCs against PRGs.
5. Develop general response actions.
6. Identify and screen technologies and process options.
7. Develop remedial alternatives.
8. Perform detailed analysis of remedial alternatives.
9. Perform comparative analysis of each alternative's ability to satisfy the evaluation criteria.

3.1 Applicable or Relevant and Appropriate Requirements

Potential ARARs are discussed in this section because they can affect the development of RAOs. After remedial alternatives have been developed, they are evaluated against whether they meet ARARs. Once a remedy is selected, final ARARs are identified in the Decision Document.

CERCLA remedial actions must meet ARARs for selected remedies. ARARs are federal, state, and local public health and environmental requirements that define the extent of site cleanup, identify sensitive land areas or land uses, develop remedial alternatives, and direct site remediation. CERCLA and the NCP require that remedial actions comply with federal ARARs and also with state and local ARARs that are more stringent than their federal counterparts, as long as they are enforceable and consistently enforced.

Where the State of Missouri is authorized to implement a program in lieu of a federal agency (for example, the National Pollutant Discharge Elimination System), state laws arising out of the state program may be ARARs, not the federal authorizing legislation.

There are three types of ARARs. *Location-specific ARARs* restrict the occurrence of chemicals in certain sensitive environments, such as wetlands (for example, the Endangered Species Act). *Action-specific ARARs* are activity-based or technology-based, and typically control remedial activities that generate hazardous wastes (for example, Resource, Conservation and Recovery Act). *Chemical-specific ARARs* are health-based or risk management-based numbers that provide concentration limits for the occurrence of a chemical in the environment (for example, USEPA MCLs).

Section 121 of CERCLA requires that primary consideration be given to remedial alternatives that attain or exceed ARARs. The purpose is to make CERCLA response actions consistent with other pertinent federal, state, and local environmental requirements and to adequately protect human health and the environment.

ARARs include promulgated environmental requirements, criteria, standards, and other limitations. Other factors are "to be considered." Factors to be considered in remedy selection may include guidance and other limitations, but attainment of them is not a threshold criterion during alternative selection. Instead, they can be used to evaluate whether the selected remedy protects human health and the environment. Implementation of the selected remedial actions must comply with ARARs, per the NCP.

Applicable requirements are cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental, state environmental, or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site. Only state standards that are identified by a state in a timely manner and that are more stringent than federal requirements may be applicable 40 Code of Federal Regulations (CFR) Part 300.5 (40 CFR 300.5).

Relevant and appropriate requirements are cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site. Only those state standards that are identified in a timely manner and are more stringent than federal requirements may be relevant and appropriate 40 CFR 300.5.

A requirement must first be determined to be relevant, then appropriate. In general, this involves a comparison of several site-specific factors, including the characteristics of the remedial action, the nature of the hazardous substance present at the site, and applicable regulatory requirements. In some cases, a requirement may be relevant but not appropriate; it is possible for only a part of a requirement to be considered relevant and appropriate in a given case. When the analysis results in a determination that a requirement is both relevant and appropriate, such a requirement must be complied with as if it were applicable.

To be considered factors are advisories or guidance issued by federal, state, or local government that are not legally binding and do not have the status of potential ARARs. In many circumstances, such factors are considered along with ARARs in determining the level of cleanup required to protect human health and the environment.

Remedial actions must comply with federal, state, and local ARARs. For a state or local requirement to be an ARAR, it must satisfy three criteria:

- It must meet the definition of an ARAR.
- It must be more stringent than federal requirements.
- It must be a promulgated standard, requirement, criterion, or limitation under a state or local environmental or facility siting law and consistently enforced.

Table 3-1 lists statutes and regulations containing requirements deemed potential ARARs.

3.2 Remedial Action Objectives

RAOs are goals specific to media or operable units for protecting human health and the environment. The identified risks can be associated with current or potential future exposures. RAOs should be as specific as possible but not so specific that the range of alternatives that can be developed is unduly limited. Objectives aimed at protecting human health and the environment should specify (1) COCs; (2) exposure routes and receptors; and (3) an acceptable contaminant level or range of levels for each exposure route (that is, a PRG) (USEPA 1988).

RAOs were developed for the site in part based on the contaminant levels and exposure pathways found to pose potentially unacceptable risk to human health, as determined during the RI. The RAOs, remediation goals, and remediation strategies developed address constituents posing unacceptable risk under the exposure scenarios evaluated during the RI.

As stated in Section 2, groundwater COCs were identified for the potable use exposure pathway. However, St. Louis Ordinance 66777, which prohibits the installation of potable water supply wells, is already in place as an institutional control and removes the exposure pathway for onsite and offsite receptors to use the groundwater as a potable resource.

COC concentrations in various environmental media at the site pose unacceptable risks to human health based on the various exposure pathways. Therefore, the following RAOs were developed for the site:

- Prevent unacceptable risk to future human receptors (onsite and offsite) from potential vapor intrusion to indoor air.
- Prevent unacceptable risk to residents from ingestion of onsite soil containing antimony and thallium within Exposure Units E, I, J, and K.
- Prevent unacceptable risk to onsite construction workers from dermal contact with groundwater containing CT and PCE.
- Remove soil to prevent future human exposure to onsite soil with elevated concentrations of arsenic, lead, and Aroclor 1260 at the following historical sample locations:
  - Sample NS03A arsenic at 44 mg/kg; lead at 5,840 mg/kg
  - Sample NS08A arsenic at 67.7 mg/kg
  - Sample SS-001 Aroclor 1260 at 1.4 mg/kg
  - Sample SED-001 Aroclor 1260 at 569 mg/kg
  - Sample SS-218A-2 lead at 2,724 mg/kg
  - Sample SS-219B arsenic at 108 mg/kg
  - Sample SS-219C arsenic at 68.8 mg/kg
  - Sample SS55A Aroclor 1260 at 18,200 mg/kg
- Remove the sediment within onsite powder wells to prevent future human exposures.

3.3 Preliminary Remediation Goals

PRGs are risk- or ARAR-based chemical-specific concentrations that help refine the RAOs. PRGs are considered preliminary, in that the final remedial goals are defined in the Decision

Document once a remedy is selected for the site. The PRGs are used to define the extent of contaminated media requiring remedial action. The following sections contain the PRGs for COCs in soil and groundwater. PRGs for the sediment in the powder wells were not calculated, because sediment will be removed from the wells as part of the remedial action at the former Hanley Area.

3.3.1 Soil

PRGs identified for soil COCs to prevent unacceptable risk to residents from ingestion of onsite soil containing thallium and antimony within Exposure Units E, I, J, and K and to prevent unacceptable risk to human receptors to onsite soil containing elevated concentrations of arsenic, lead, and Aroclor 1260 consist of the following:

- Thallium 7 mg/kg
- Antimony 31 mg/kg
- Lead 400 mg/kg
- Arsenic 13.2 mg/kg
- Aroclor 1260 1 mg/kg

The PRGs for thallium, antimony, and lead are the Regional Screening Levels for residential soil based on a noncancer hazard index of 1.0 (USEPA 2009a). Table 3-2 presents the PRG calculations for arsenic and Aroclor 1260. The Aroclor 1260 PRG is based on a "to be considered" ARAR (40 CFR 761.61(a)(4)(I)(A)) rather than an actual site calculation.

Although PRGs were developed for arsenic, lead, and Aroclor 1260, the HHRA did not identify those chemicals as COCs. Elevated concentrations of arsenic, lead, and Aroclor 1260 had been excluded from the HHRA, because project stakeholders agreed that areas where these chemical concentrations were elevated would be addressed through a future soil removal action. PRGs for arsenic, lead, and Aroclor 1260 will serve as cleanup criteria when the Army performs the removal action. Because the remaining concentrations do not pose unacceptable risk to human health, arsenic, lead, and Aroclor 1260 do not require additional remedial action beyond the soil removal areas previously identified.

Figure 3-1 shows the locations designated for soil removal. Antimony was not detected at a concentration above its PRG; therefore, no additional action is necessary for antimony.

3.3.1.1 Development of Arsenic PRG

The arsenic PRG was discussed in during a teleconference on January 22, 2010, among the Army, CH2M HILL, MDNR, Missouri Department of Health and Senior Services, and USEPA Region 7. The project stakeholders agreed to develop an arsenic PRG using methods presented in the February 2005 Final Background Characterization for Lake City Army Ammunition Plant (LCAAP) (ARCADIS G&M 2005), incorporating updated USEPA recommendations (e.g., ProUCL approaches to calculating background threshold values).

In accordance with the January 22, 2010 teleconference, the Army completed the following steps to develop a PRG for arsenic in soil:

- Select a sample population of arsenic concentrations in soil at the former Hanley Area. Remove outliers from the sample population.

- Construct a probability plot of the remaining concentrations. Identify the most likely inflection point that distinguishes background and site-related concentrations.
- Calculate the upper tolerance limit from the concentrations below the inflection point value.

Sample Population and Outlier Evaluation. To develop the arsenic PRG, an outlier analysis was performed on a population of 116 samples from the 0-to-10-foot depth interval that was used to estimate sitewide construction worker risk in the HHRA. Appendix B, Table 1 presents the individual arsenic concentrations, sorted in order of decreasing concentration, used to construct the probability plot.

Visually, two elevated results (23.5 and 36.3 mg/kg) appeared unusual relative to the rest of the data. The two values were the only values identified as mathematical outliers using Rosner's outlier test. No other values in either the elevated or the lower tail of the concentrations were mathematical outliers. The two elevated results were excluded from the data used to prepare probability plots.

Probability Plot Interpretation. Probability plots provide a visual tool for identifying possible inflections or breakpoints in the dataset. They graph actual concentrations against theoretical quantiles assuming that the true distribution of the data is normal. The quantiles are the number of standard deviations from the mean for the theoretical dataset, assuming the data are distributed normally. Transformations (e.g., log-transformations) are sometimes explored to determine whether the transformed data might be normal, even when the raw data are not.

If a dataset contains both naturally occurring and affected samples, one might expect the two distributions to appear as separate representations on the probability plot. Although it is possible for the impact to be so small in many samples that the plot maintains a smooth curve, it is also possible that the affected data will cause a clear inflection in the curve. The appearance of an inflection can serve as a marker for the onset of the affected data, and the naturally occurring concentrations are those values with lower concentrations than the inflection point. When the data are approximately distributed normally, the resulting plot is a straight line. When deviations from normality occur, the plot veers from a straight-line pattern, including some inevitable curvature in the tails (unless the sample size is extremely large).

Three probability plots were prepared (see Appendix B). In Exhibit 1, a normal probability plot is presented using untransformed data where ½ the detection limit open circles portray the nondetect values. In Exhibit 2, a normal probability plot is presented using only untransformed detected values. In Exhibit 3, natural log-transformed detected values are presented. Each plot depicts a potential inflection point between concentrations of 11.7 and 13 milligrams per kilogram (mg/kg). Based on the inflection points depicted in the exhibits, all results below the inflection point (that is, less than 13 mg/kg) were considered as background values for calculation of a background threshold value; in this case, the 95/95 upper tolerance limit.

Calculation of the Upper Threshold Limit. The upper tolerance limit was calculated following the algorithms from ProUCL (USEPA 2009b). This included determining the most appropriate distributional assumption, which was the normal distribution.

In the presence of nondetected concentrations, ProUCL attempts to calculate a upper tolerance limit based on maximum-likelihood-estimate (MLE) proxies for the nondetects. For instance, it will attempt to attribute proxy values for the nondetects that will optimize fit to the distribution ProUCL otherwise chose. When an upper tolerance limit based on MLE proxies is available, it is preferred, per discussion in the ProUCL Technical Guide (USEPA 2009b), to use an upper tolerance limit calculated using proxy values for nondetects of the detection limit divided by 2. Thus for arsenic, the MLE Normal upper tolerance limit was recommended from ProUCL.

The calculated MLE Normal upper tolerance limit of 13.2 mg/kg is recommended as the appropriate background threshold value. Individual site concentrations less than this threshold value will be considered indistinguishable from background concentrations. This value will be used as the PRG for arsenic in soil at the former Hanley Area.

3.3.2 Groundwater

3.3.2.1 Construction Worker Dermal Contact

PRGs identified to prevent unacceptable risk to onsite construction workers for dermal contact with COCs in groundwater consist of the following:

- CT 3,200 μg/L
- PCE 21,000 μg/L

Tables 3-3 and 3-4 present the PRG calculations based on potential risk to construction workers. Figure 3-2 shows the locations where COCs exceed their respective PRGs.

Risks were not identified for soil containing CT and PCE. However, concentrations of CT and PCE in the unsaturated soil may affect the RAO for construction worker dermal contact with groundwater. Therefore, PRGs were developed for unsaturated soil to address potential ongoing sources of groundwater contamination. The following PRGs were developed:

- CT 1.19 mg/kg
- PCE 9.14 mg/kg

These PRGs are based on the site-specific calculations using a dilution attenuation factor of 1 and are presented in Table 3-5. The PRG calculations are presented in Tables 3-6 and 3-7.

3.4 Summary of Areas for Further Action

Based on the RAOs and the areas with COC concentrations above the PRGs, target treatment zones (TTZs) were developed for areas that require further action at the former Hanley Area for surface soil, sediment within the powder wells, and groundwater. Further action also may be required to address future vapor intrusion risk.

3.4.1 Surface Soil

Two areas where thallium concentrations exceed the PRG of 7 mg/kg need to be addressed. They are the areas associated with samples SS-218A-1 and SS-218A-3 (Figure 3-1). The TTZ for surface soil will encompass the non-concrete-covered areas around those samples. The estimated TTZ volumes are as follows:

- 30 cubic yards around SS-218A-1
- 90 cubic yards around SS-218A-3

The concentrations of antimony were below the PRG, so antimony requires no further action.

The TTZ volumes associated with historical sample locations designated for soil removal during the RI phase are listed below and shown in Figure 3-1:

- 20 cubic yards around NS03A (arsenic = 44 mg/kg; lead = 5,840 mg/kg)
- 90 cubic yards around NS08A (arsenic = 67.7 mg/kg) and SS-219B (arsenic = 108 mg/kg)
- 65 cubic yards around SS-001 (Aroclor 1260 = 1.4 mg/kg), SED-001 (Aroclor 1260 = 569 mg/kg), and SS55A (Aroclor 1260 = 18,200 mg/kg)
- 50 cubic yards around SS-218A-2 (lead = 2,724 mg/kg)
- 85 cubic yards around SS-219C (arsenic = 68.8 mg/kg)

3.4.2 Powder Well Sediment

The volume of sediment within the powder wells is estimated to be 28 cubic yards. Figure 3-1 shows the locations of the powder wells.

3.4.3 Groundwater

As noted, St. Louis Ordinance 66777 prohibits potable use of onsite and offsite groundwater. No further action is required to address residential exposure to groundwater. However, further action is required to address groundwater concentrations that exceed PRGs to onsite construction workers. For this reason, groundwater PRGs were developed for CT and PCE.

The area with groundwater concentrations of CT above the PRGs (Plume C) is deeper than 10 feet, the maximum depth for which construction worker exposures are considered. The HHRA conservatively evaluated groundwater risk by assuming that groundwater across the entire site lies within 10 feet below ground. However, as discussed in subsection 2.3.3.3, the depth to groundwater within Plume C is greater than 10 feet. For this reason, no further action is required for CT.

The area with groundwater containing PCE concentrations above the PRGs is near former Building 220 and includes an estimated volume of 3,500 cubic yards. The part of the area below Stratford Avenue is inaccessible (Figure 3-2); therefore, the volume within the TTZ is 2,250 cubic yards.

3.4.4 Vapor Intrusion

The HHRA determined that future indoor air exposures within the buildings on the site may be at unacceptable levels because of high groundwater concentrations detected and shallow groundwater depths. Because further migration of the groundwater plume is possible (subsection 2.4.4), future risk associated with offsite indoor air exposures is also possible. Because of the uncertainty associated with this exposure pathway, the remedial design and remedies will include a vapor intrusion evaluation. In accordance with the U.S. Army vapor intrusion policy, notification will be given to current property owners (onsite and offsite) of potential vapor intrusion risk (U.S. Army 2006).

3.5 General Response Actions

After the RAOs and PRGs were developed, GRAs were identified to address the RAOs and PRGs for affected media at the site. As defined in the USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final,* GRAs are media-specific actions that satisfy RAOs. Actions for mitigating risk posed by affected media may be applied individually or in combination. Table 3-8 summarizes the development of GRAs for achieving the RAOs in groundwater and saturated soil. GRAs for unsaturated surface soil and sediment were not developed because the lead agency (U.S. Army) and lead regulatory agency (MDNR) agreed to address the COCs in soil by removal and offsite disposal. Since removal and disposal activities are being conducted for metals and a PCB within and near the areas with thallium concentrations above the PRGs, removal and disposal is the recommended remedial action to address thallium in soil.

3.6 Technologies and Process Options

Within each remaining general response action, remedial technologies were identified and screened using the following criteria:

- **Effectiveness** is the ability of the technology or process option to perform adequately to achieve the remedial objectives alone or as part of an overall system.
- **Implementability** refers to the relative degree of difficulty expected in implementing a particular measure under practical technical, regulatory, and schedule constraints.
- **Relative cost** is comparative only and is judged similarly to effectiveness. It is used to preclude further evaluation of process options that are very costly when there are other choices that perform similar functions with comparable effectiveness. It includes construction and long-term operation and maintenance (O&M) costs.

Table 3-9 summarizes the screening process for groundwater and saturated soil. Technologies and process options considered infeasible based on effectiveness, implementability, and costs are shaded. Screening was based on professional experience, published sources, and other relevant documentation. The technologies retained following screening include no action, monitoring, in situ treatment, removal, and disposal.

3.7 Limitations of Certain Remedial Technologies in Fine-Grained Soils

One aspect of the site that significantly influenced the selection of remedial technologies retained for detailed evaluation is the nature of the shallow geologic setting in which the contamination is present, specifically the preponderance of clay soil throughout the overburden across the former Hanley Area. Fine-grained soil of this type presents a challenging remediation environment for many groundwater remediation technologies and limits their remediation performance.

A fine-grained soil environment may reduce the effectiveness of groundwater remediation technologies that rely on extraction of fluids or injection of liquid or solid reagents. Such technologies include the following:

- **Pumping and treatment.** Pumping and treatment relies on extraction of groundwater for its effectiveness. Extraction of groundwater from clayey aquifers typically is neither efficient nor effective. Groundwater recovery rates are low in these types of aquifers, and the achievable radius of influence for individual recovery wells is limited. Tight well spacing with many small extraction pumps or a jet pump type system usually is required. O&M costs for such systems typically are high. It is difficult to predict when remediation will be complete using this technology.
- **Dual-phase extraction.** Dual-phase extraction extracts both groundwater and soil vapor to achieve remediation goals. When applied in a clayey hydrogeologic setting, the groundwater extraction aspect of dual-phase extraction has the same limitations as pumping and treatment. Soil vapor extraction (SVE) typically is neither effective nor efficient in this geologic setting, and the radius of influence achieved by SVE is limited. O&M costs for dual-phase extraction systems in clayey settings typically are high. It is difficult to predict when remediation will be complete using this technology.
- **In situ chemical oxidation using liquid phase injection**. In situ oxidation as applied for chlorinated solvents in contaminated aquifers typically relies on liquid phase injection of solutions containing an oxidant and, in some cases, an activator. Typical oxidants used include potassium/sodium permanganate, sodium persulfate, and catalyzed hydrogen peroxide. Experience with injection of liquid phase oxidants into predominantly clayey aquifers has shown that injection rates are low, the achievable radius of influence is limited, and the distribution of the oxidant throughout the formation is nonuniform, leaving parts of the aquifer untreated. For this reason, multiple rounds of injection are required. Even with multiple rounds of injection, it generally is not possible to achieve completely uniform treatment of the aquifer. Contaminant rebound may be observed several years after treatment has been completed because of diffusion of residual, untreated contamination from low permeability zones in the formation. It is not possible to estimate the number of required injections before implementing in situ chemical oxidation to reach site closure or whether rebound will occur after the final round of injections.
- **In situ chemical reduction using liquid or gaseous phase injection**. Injection of chemical reductants, such as zero valent iron, emulsified zero valent iron, or Adventus's EHC, can achieve chemical reduction of many cVOCs. Most reductants commonly used to treat contaminated aquifers are available only in particulate form. Experience has shown that liquid phase injection of solutions containing these particulate reagents, even in sandy formations, is not practicable as the particulates are quickly strained out by the aquifer close to the injection points, leading to sealing off of the formation around the injection points and preventing further injection. This precludes the injection of significant quantities of reagent and limits the radius of influence. To circumvent this

problem, pneumatic fracturing is used for reagent delivery. Although this has.allowed delivery of particulate reagents into aquifers, including clayey aquifers, the delivery method shares many of the same problems as the delivery of liquid reagents into clayey aquifers. Experience with this form of remediation has shown that uniform delivery of particulate reagents throughout the formation cannot be guaranteed. As with the application of liquid phase reagents, the number of rounds of pneumatic injections required to achieve complete remediation cannot be predicted before implementing this remediation method. Rebound of contamination several years after the last round of injections is completed may occur for the same reason noted for liquid phase reagent injection.

- **In situ bioremediation using anaerobic reductive dechlorination.** This commonly applied technology for treating cVOCs in groundwater relies on delivering an organic substrate to the aquifer to stimulate groundwater bacteria to degrade the contaminants. Delivery of the substrates, such as sodium lactate, emulsified vegetable oil, or other commercially available substrates, most frequently is done using liquid phase injection, but pneumatic fracturing methods also have been used to deliver them. When applied in a clayey soil, many of the problems described for in situ chemical oxidation and in situ chemical reduction may occur with this technology, such as limited injection rates, relatively small radius of influence, nonuniform distribution of reagents, difficulty in predicting how many rounds of injection will be required to complete the remediation, and possible rebound several years after the final injections have been completed.

Experience has shown that achieving robust reductive dechlorination at sites with low permeability formations and low seepage velocities (e.g., less than 30 feet per year) is often challenging. Groundwater velocities should be greater than 30 feet per year for a site to be suitable for an in situ biological treatment zone. Sites with groundwater velocities less than 20 feet per year are considered unsuitable for in situ biological treatment zones (Suthersan and Payn 2005). One reason for this is that, because the reductive dechlorination process relies on a syntrophic population of interdependent bacteria, each performing a different function in the degradation process, a certain level of advective flow through the system is needed for optimal biodegradation activity. The low permeability and low flow rates in overburden soils may be a reason that reductive dechlorination, while occurring at the site, is not occurring robustly.

For the reasons noted above, technologies that rely on fluid extraction or injection of liquid or particulate reagents are not expected to perform well in the hydrogeologic setting of the former Hanley Area. Although each technology could be made to work, to some degree—by installation of a large number of closely spaced extraction or injection points, and repeated applications of reagents—the time to reach cleanup would be somewhat indeterminate and application may not be cost-effective. For these reasons, only technologies whose performance is not expected to be limited by the hydrogeologic setting of the site were retained for detailed evaluation.

3.8 Remedial Alternatives

The technologies that remained following screening were assembled into remedial alternatives that meet the RAOs for the site. The specific details of the remedial components of each alternative are intended to serve as representative examples to allow order-of-magnitude cost estimates. Process options within the same remedial technology that achieve the same objectives may be evaluated during the remedial design.

The following remedial alternatives were evaluated:

- Alternative 1 — No Action
- Alternative 2 — In Situ Groundwater Treatment Using Thermal Technologies, Soil and Powder Well Sediment Removal, and Offsite Disposal
- Alternative 3 — In Situ Groundwater Treatment and Soil and Powder Well Sediment Removal and Offsite Disposal
- Alternative 4 — Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal, and Offsite Disposal

Appendix A contains cost estimates for the proposed remedial alternatives.

3.8.1 Alternative 1—No Action

Alternative 1 consists of taking no action. The NCP requires that a No-Action Alternative be retained throughout the FS process as a baseline for comparison to the other approaches. No action would leave affected soil, groundwater, and powder well sediment in place at the site. No mechanisms would be in place to prevent or control exposure to contaminants. Alternative 1 allows natural processes such as dispersion, degradation, and dilution to reduce contaminants. Lack of active cleanup or controls may allow receptors to be exposed to contaminants. There are no capital or O&M costs for the Alternative 1. Therefore, a cost estimate was not necessary.

3.8.2 Alternative 2—In Situ Groundwater Treatment Using Thermal Technologies, Soil and Powder Well Sediment Removal and Offsite Disposal

Alternative 2 relies on in situ thermal technologies to reduce PCE concentrations within the Plume A TTZ (Figure 3-2), which corresponds to the area where groundwater concentrations exceed construction worker PRGs but does not extend into Stratford Avenue. Alternative 2 includes removal and offsite disposal of metals and Aroclor 1260-contaminated surface soil to address the soil TTZs and powder well sediment and a vapor intrusion evaluation. Five-year site reviews are included in Alternative 2 as they are required for sites containing COC concentrations above respective remediation goals.

Alternative 2 includes treatment of the groundwater TTZ to address direct contact risk to construction worker within Plume A as described below. Groundwater monitoring will be performed within Plume C to confirm that the exposure pathway between construction workers and contaminated groundwater remains incomplete as long as concentrations of CT remain above the risk threshold for direct contact risk to construction workers. Details of the monitoring program, such as number and location of wells to be sampled, will be provided in the remedial design. For cost estimating, it is assumed that groundwater samples and depth to water measurements will be conducted annually for the first 5 years.

3.8.2.1 Thermal Treatment of Groundwater

Thermal treatment processes work by increasing the temperature of the contaminated soil and groundwater through the introduction of steam or electrical energy. The primary in situ heating processes include steam-enhanced extraction, electrical resistance heating (ERH), and thermal conductive heating (TCH). Heat is the driving force for in situ remediation processes during thermal treatment. The process is relatively unaffected by contaminant distribution, concentration, chemical structure, or toxicity. Effectiveness is attributable to the increase in mobility and mass transfer properties of VOCs. Enhancement of these physical properties by heating accelerates both the rate and extent of VOC mass recovery from the target treatment area. Thermal treatment can also catalyze in situ destruction processes for contaminants; mechanisms responsible for removal are specific to both the contaminant and the heating methodology applied.

Although both ERH and TCH could conceptually work effectively at the site, TCH would be the more robust technology because of the clayey hydrogeologic setting. Recent applications have shown that ERH has not performed as well as TCH in clayey sites, since ERH relies on saturated soil conditions in the treatment zone to conduct electrical current effectively. When ERH technology is applied in clayey soils, the soils often dry out, decreasing their ability to conduct electrical current and thus reducing the degree to which they are heated. Because of the low permeability of the formation, groundwater outside the treatment zone cannot migrate quickly enough into the formation to maintain saturated conditions. TCH technology does not have this limitation and has been effectively applied in clayey soils without loss in efficiency from drying of the soil. For this reason, the discussion below provides more detail on TCH, which is more suitable for the site and therefore was assumed for costing purposes.

Thermal Conductive Heating Description. In TCH systems, heat and fluid extraction are applied simultaneously to subsurface soils using an array of vertical heaters and extraction points. The heating process in TCH (as opposed to ERH) is effective in both saturated and unsaturated zones and is well-suited to applications with heterogeneous site conditions such as this site. TCH is also effective at remediating NAPL, if present, from the subsurface.

A continuous, sealed steel casing is installed using conventional drilling techniques. Within the casing, a heater element is suspended over the depth of heating area desired for treatment. A typical heater assembly consists of a U-shaped metal rod 0.5 inch in diameter installed in a section of sealed well casing. Ceramic insulators are used to electrically isolate the heating element from the steel casing. The annulus around the heater element is open to air. When electrical current is applied to the heater element, resistance occurs and heat is generated. From the heater element, radiant heat is transferred to the well casing; from the steel well casing, heat is transferred to the surrounding subsurface materials by conduction. Sustained heating of the treatment area will then vaporize the water within the soil matrix. The resulting effect is the transfer of heat in the treatment zone by convective mechanisms. The heaters used are capable of achieving temperatures approaching 900°C. Since the transfer of heat relies on conduction, which is not limited by the boiling properties of water (as with ERH), treatment temperatures greater than 500°C can be achieved in situ.

Applications employing the TCH technology and targeting treatment temperatures near 100°C have been successfully applied in the treatment of chlorinated solvents in unsaturated and saturated soil, groundwater, and most recently, fractured rock. The TTZ will be heated to at least 100°C (212°F) to boil off water within the TTZ. Contaminant reduction is expected to be better than 99 percent for PCE. VOCs adsorbed to soil within the target treatment zone are expected to be remediated, as are residual droplets of NAPL that might be present in the heated treatment volume. TCH is applicable in most hydrogeologic conditions, including tight soils, clay, or soils with wide heterogeneity in permeability or moisture content.

Arrangement of the heating and extraction infrastructure in the TTZ using five- and seven-spot configurations is common. Heater spacing is site-specific and controlled by the required heating objectives, desired operating duration, and subsurface conditions (for example, saturated or unsaturated treatment). Typical heater spacing is 12 to 20 feet for low temperature applications (100°C for the treatment of chlorinated solvents). To minimize subsurface borings required for system installation, combination heater-vacuum wells have been developed. Vapor or multi-phase fluid recovery in the combined heater point is achieved by an independent but collocated extraction point. Variation on the combined heater-vacuum strategy also allows for nested construction whereby the heater is suspended within the annulus of the vapor recovery well.

Upon subsurface heating, contaminants and NAPLs are vaporized and captured by vapor and groundwater extraction systems. Extracted fluids, including groundwater, soil vapor, and steam, are subsequently treated above ground. A typical treatment process may include a heat exchanger, chiller, or cooling tower followed by separation of liquid and vapor. Recovered fluids are generally treated using granular activated carbon, vapor treatment using adsorption, thermal oxidation, or by applying condensation technologies. Ancillary infrastructure for TCH includes systems for in situ temperature and pressure monitoring, electrical power distribution equipment, and a control room trailer. The treatment area may be covered with an impermeable and insulating surface seal to prevent infiltration of precipitation into the treatment area, and to minimize surface heat losses and short-circuiting of the vapor extraction system.

Time required to heat the subsurface and achieve remedial goal varies, depending on site conditions, well spacing, and PCE concentrations. Implementation strategies for TCH are based on the physical and chemical properties of PCE. Therefore, the selection of the target temperature is based on the desired treatment approach: enhanced extraction or thermal destruction (by oxidation, hydrolysis, or pyrolysis). Surface blanket heaters incorporating TCH principals can be used to treat shallow soil contamination, but this approach is much less common.

Application of Thermal Conductive Heating at Former Hanley Area. As part of this alternative, TCH would be applied within a TTZ of 45 by 45 feet and 30 feet below ground (Figure 3-2), the estimated area that exceeds the PCE PRG for the construction worker, direct contact exposure pathway. This alternative assumes that the 40- by 40-foot concrete pad would be demolished and disposed of offsite before treatment. Before thermal treatment, a groundwater sampling event would be conducted to refine the extent of the TTZ. Sampling will be performed following completion of the remedial action to evaluate the effectiveness of the remedy in meeting the PRG for construction workers.

Sampling of soil during active thermal treatment is difficult and typically not conducted for several reasons. The presence of treatment system components on the ground surface above the treatment zone, such as liners and covers, electrical conduits and vapor recovery manifolds and piping, make access for drilling and sampling of soil and groundwater difficult. Elevated temperature may cause steam to be present in the wells, creating a potential hazard during sampling. At sites at which ERH or TCH is being implemented, groundwater elevations within the thermally treated area may decline significantly, possibly below the elevation of the screened interval, making sampling of these wells impracticable. If groundwater samples are collected, the elevated temperature of the groundwater may also contributed to excessive loss of VOCs during sampling.

For these reasons, performance verification sampling is conducted after the thermal treatment system has been shut down and sufficient cooling has occurred to allow for representative samples to be collected. In situ thermal remediation systems are operated until the project team determines that an appropriate duration of thermal treatment has been achieved. This determination is made using a weight of evidence approach, that includes factors such as actual treatment time versus the expected duration of thermal treatment, amount of mass recovered, observations that the amount of mass being recovered, as measured in the recovered soil vapors, has reached a point of diminishing returns, review of data regarding temperatures achieved within the treatment zone from thermocouples, amount of power delivered to the subsurface, and other relevant information. Based on information provided by TerraTherm, treatment time (following installation of the thermal system) is estimated to be less than 6 months to achieve remediation goals onsite.

Annual groundwater sampling within the treatment area will be collected as part of the vapor intrusion evaluation and Plume C monitoring. Data collected within the Plume A treatment area will also be used to evaluate the degree of contaminant removal. If further treatment is required, the system may be re-started.

3.8.2.2 Soil and Powder Well Sediment Removal

This alternative consists of excavating an area of metals and Aroclor 1260-contaminated surface soil, transporting it offsite, and disposing of it at a permitted landfill. Before excavation, hand auger soil borings would be advanced to delineate the presence of COCs in soils around sample locations:

- Sample SS-218A-1 thallium at 8.64 J mg/kg
- Sample SS-218A-3 thallium at 7.67 J mg/kg
- Sample NS03A arsenic 44 at mg/kg; lead at 5,840 mg/kg
- Sample NS08A arsenic 67.7 at mg/kg
- Sample SS-001 Aroclor 1260 at 1.44 mg/kg
- Sample SED-001 Aroclor 1260 at 569 mg/kg
- Sample SS-218A lead at 2,724 mg/kg
- Sample SS-219B arsenic at 108 mg/kg
- Sample SS-219C arsenic at 68.8 mg/kg
- Sample SS55A Aroclor 1260 at 18,200 mg/kg

Utilities would be marked before excavation. Excavation would be conducted using a backhoe. It is assumed for cost estimating purposes that excavation would be required to a depth of 2 feet below ground in areas not covered with concrete, but the depth will be determined based on confirmation sampling conducted before excavation. Soil samples from the area would be collected and analyzed for the corresponding COC to determine excavation limits. Estimated excavation limits are shown on Figure 3-1. Samples of the soil would be collected for disposal characterization. The excavated soil would be disposed of offsite at a permitted Subtitle D landfill. This alternative assumes that the excavated soil would not be characterized as hazardous waste. Following excavation and confirmation sampling, the area would be backfilled, regraded, reseeded, and restored to its original condition. Clean, imported material would be used as backfill.

If sediment is present in the 22 powder wells shown in Figure 3-1, it would be removed and disposed of offsite at a permitted Subtitle D landfill.

3.8.2.3 Vapor Intrusion Evaluation

Based on the uncertainty of indoor air risk, the vapor intrusion pathway will be further evaluated as part of the site remedy. Several components may be included in the evaluation, such as:

- Vapor migration information collected from similar sites
- Site-specific VOC data
- Data collection methods developed by the industry
- Vapor intrusion modeling
- Potential risk based on current structures or future structures

For cost estimating purposes, the vapor intrusion evaluation will include monitoring the VOCs in groundwater that were observed above the screening levels listed below.

- Benzene: 5 µg/L
- CT: 5 µg/L
- Chloroform: 1.9 µg/L
- 1,2-DCA: 5 µg/L
- *cis*-1,2-DCE: 70 µg/L
- *trans*-1,2-DCE: 100 µg/L
- Naphthalene: 6.2 µg/L
- 1,1,1,2-TeCA: 5.2 µg/L
- 1,1,2,2-TeCA: 0.67 µg/L
- 1,1,2-TCA: 5 µg/L
- PCE: 5 µg/L
- TCE: 5 µg/L

These screening levels are the MCLs, except for chloroform, naphthalene, 1,1,1,2-TeCA, and 1,1,2,2-TeCA. Resident risk-based screening levels for potable use were developed for these chemicals (see Tables 3-10 and 3-11). The area with VOC concentrations above the screening levels are shown in Figure 2-6.

If the vapor intrusion evaluation concludes that there is risk to human receptors, additional sampling or mitigation actions such as vapor barriers or in-home mitigation systems that vent indoor air to the atmosphere may be implemented.

The details of the vapor intrusion groundwater monitoring program, such as the number and location of wells to be sampled and the frequency will be provided in the remedial design. For cost estimating, it is assumed that groundwater samples would be conducted annually for the first 5 years to establish groundwater trends and areas that may be susceptible to indoor air risk. Following Year 5, groundwater samples would be collected every 5 years to monitor the above VOCs at the site to identify changes in the plume that might affect the protectiveness of the selected remedy. Because vapor intrusion is an evolving field, groundwater sampling may be replaced with modeling or other sampling methods, as new technologies become available during the remedial design, remedial action, or long-term management. Data available or collected as part of the remedial design may be used to adjust the remedial approach if appropriate.

3.8.2.4 Five-Year Reviews

As part of this alternative, 5-year site reviews are included as long as hazardous substances remain at the site at concentrations that do not allow unlimited use and unrestricted exposure, per the NCP. The implementation of the remedial action will be considered complete once COCs are at or below the remediation goals, the vapor intrusion pathway is determined not to cause unacceptable risk (or chemical concentrations in groundwater fall below screening levels), and monitoring confirms that no unacceptable risks are posed by Plume C. Once these conditions are confirmed at the former Hanley Area, the five-year reviews will be terminated.

The 5-year review will focus on vapor intrusion, the only potential risk that will not be actively addressed through remedial action, and monitoring results associated with Plume C to confirm that the construction worker risk exposure remains unchanged. The time that natural attenuation takes to return groundwater to the potable use levels is estimated to be more than 84 years for Alternatives 2, 3, and 4. This duration is considered comparable to the time required to remove risk associated with vapor intrusion. For cost estimating purposes, the estimated duration of Alternatives 2, 3, and 4 was chosen as 50 years. Although the actual monitoring period may be 100 years, cost estimating periods beyond 50 years have little effect on the present worth estimate.

Appendix A contains the cost estimate to implement this alternative.

3.8.3 Alternative 3—In Situ Groundwater Treatment and Soil and Powder Well Sediment Removal and Offsite Disposal

Alternative 3 relies on in situ groundwater treatment using chemical processes known as chemical reduction or chemical oxidation to reduce PCE concentrations in groundwater TTZ (Figure 3-2), removal and offsite disposal of metals and Aroclor 1260-contaminated surface soil and sediment within existing powder wells, and a vapor intrusion evaluation. Five-year site reviews are included in Alternative 3 as they are required for the vapor intrusion pathway due to uncertainty in the risk assessment. Remedial action details regarding the items below are provided in Section 3.8.2 above.

- Groundwater monitoring for Plume C
- Removal and offsite disposal of metals and Aroclor 1260-contaminated surface soil and sediment within the powder wells
- Vapor intrusion evaluation
- Five-year site reviews

Under Alternative 3, the groundwater TTZ would be treated by applying a chemical reductant or oxidant to in situ soil and groundwater. Based on limitations of chemical oxidation and injection applications, chemical reduction using soil mixing procedures was selected as the basis of the cost-estimate and is described in further detail. The actual in situ application will be developed as part of the remedial design.

Mechanical soil mixing involves using an in situ blender (i.e., large diameter auger or trenching machine) to effectively distribute chemical amendments throughout the soil medium to treat PCE through reductive dechlorination. At some sites, clay may also be mixed into the soil, to reduce the soil's hydraulic conductivity after treatment. Reducing the hydraulic conductivity of the treated area reduces the amount of residual contaminant flux from the source zone after treatment. The mixing of zero valent iron (ZVI) combined with clay using large diameter soil augers is a patented technology developed by DuPont, which donated the patent to Colorado State University. This process has been successfully applied at the field-scale at six sites since 2002, including four Department of Defense sites, at depths up to 35 feet below ground. This process is practicable and implementable at the site and is compatible with the clayey soils found at the site.

Soil mixing can also be performed using a one-pass trencher. This method for delivery of a controlled-release carbon and ZVI amendment is used for cost estimating in this FS. The amendment and mixing mechanisms would be selected as part of the remedial design. Due to existing utilities and roadways, COCs at concentrations greater than the PRGs located downgradient of the property, but upgradient of Stratford Avenue may not be addressed during soil mixing activities.

The one-pass trenching machine that would be used resembles a large chainsaw that is mounted on an excavator platform. This alternative assumes that the 40- by 40-foot concrete pad would be demolished and removed before treatment. The amendment is then pumped (or spread during dry applications) into the subsurface during trenching activities, much like when a bentonite slurry is mixed during the construction of a slurry wall. The trenching process is capable of using a wet or dry mixture. The rotating cutting chain will homogenize the amendment and soil as the trencher travels along the installation path. Adjacent and parallel 3-foot-wide passes would be made within the TTZ limits.

A TTZ of 45- by 45-feet and 30 feet below ground, the estimated area that exceeds the PCE PRG for the construction worker, direct contact exposure pathway was assumed for cost estimating purposes. However, the TTZ would be delineated and refined as necessary during a remedial design sampling event conducted prior to treatment.

During mixing operations, two soil samples will be collected each day at various depths to verify proper mixing and usage of the amendment. Following mixing operations, physical, chemical, and microbiological processes combine to create strong reducing conditions that stimulate rapid and complete dechlorination of PCE. First, the organic component of the amendment is nutrient-rich, hydrophilic, and has high surface area; thus, it is an ideal support for growth of bacteria in the groundwater environment. As bacteria grow on the amendment particle surfaces, indigenous heterotrophic bacteria consume dissolved oxygen and other electron acceptors (such as nitrate and sulfate) thereby reducing the redox potential in groundwater. Finally, the small ZVI particles provide substantial reactive surface area that stimulates direct chemical dechlorination and reduction of redox potential in the groundwater by chemical oxygen scavenging. Cement may be added to the soil within the TTZ to improve soil bearing capacity for future structures. The applicability of cement would be evaluated as part of the remedial design.

After implementation of soil mixing, groundwater samples would be collected from within the treatment zone and downgradient of the treatment zone to evaluate the impact on COC concentrations in groundwater. Field work to complete soil mixing activities is expected to take about 1 month, with a treatment time of roughly 3 months based on the properties of the ZVI and chemical concentrations within the Plume A TTZ. PCE concentrations in groundwater may be below PRGs within a year.

As noted, remedial actions developed to address metals and Aroclor 1260-contaminated surface soil, powder well sediment, and vapor intrusion are the same for Alternative 3 as described in Alternative 2 (Section 3.8.2). Five-year site reviews are expected for Alternative 3 as described in Alternative 2.

Appendix A contains the cost estimate to implement Alternative 3.

3.8.4 Alternative 4—Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal and Offsite Disposal

Alternative 4 relies on soil removal to reduce PCE concentrations in groundwater within the TTZ, removal and offsite disposal of metals and Aroclor 1260-contaminated surface soil and sediment within existing powder wells, and a vapor intrusion evaluation. Five-year site reviews are included in Alternative 4 for the vapor intrusion pathway. Remedial action details regarding the items below are provided in Section 3.8.2 above.

- Groundwater monitoring for Plume C
- Removal and offsite disposal of metals and Aroclor 1260-contaminated surface soil and sediment within the powder wells
- Vapor intrusion evaluation
- Five-year site reviews

Soil excavation immediately removes the contaminated media. Alternative 4 combines physical soil removal with disposal at a permitted landfill. The TTZ is consistent with Alternatives 2 and 3 (Figure 3-2). A remedial design sampling event will delineate the TTZ before soil removal. As with the other alternatives, this alternative assumes removal and offsite disposal of the 40- by 40-foot concrete pad.

Under Alternative 4, contaminated soil would be removed using a backhoe. Contaminated soil above and below the groundwater table would be excavated from the TTZ. Some contaminated soil may have to be left in place if it is not safe or practical to be removed (e.g., would require excavation too close to utilities or the roadway). Excavation near roadways or utilities would be conducted in a manner that protects structural integrity, such as the use of sheet piling.

Excavated soil may be staged temporarily onsite until waste characterization sampling is completed. For estimating purposes, it is assumed that part of the soil would be classified as hazardous waste. Excavated soil would be placed on plastic sheeting and covered with plastic to control dust and emissions and to shield the soil from precipitation. Best management stormwater pollution prevention measure would be implemented.

Following excavation, clean imported material would be used to backfill the excavation. Fill materials would be placed in the excavation in 1-foot lifts and compacted. The area would be regraded, reseeded, and restored to its original condition. Field work to complete excavation activities is expected to take approximately two months, with an immediate treatment time.

As stated above, remedial actions developed to address metals and Aroclor 1260-contaminated surface soil, powder well sediment, and vapor intrusion are the same for Alternative 4 as described in Alternative 2 (Section 3.8.2). Five-year site reviews are expected for Alternative 4 as described in Alternative 2.

Appendix A contains the cost estimate to implement Alternative 4.

3.9 Detailed Analysis of Remedial Alternatives

The detailed analysis of alternatives presents the information needed to compare the remedial alternatives. The analysis consists of a detailed evaluation of each alternative against the evaluation criteria, followed by a comparative evaluation.

3.9.1 Evaluation Criteria

The evaluation criteria allow comparison of the relative performance of the alternatives and provide a means for identifying their relative advantages and disadvantages. In accordance with the NCP, remedial actions must accomplish the following:

- Protect human health and the environment.
- Attain ARARs.
- Be cost-effective.
- Use permanent solutions and alternative treatment technologies or resource-recovery technologies to the maximum extent practicable.
- Satisfy the preference for treatment that reduces toxicity, mobility, or volume as a principal element.

Nine criteria, defined by CERCLA, are used to evaluate the cleanup options (e.g., Alternatives). Alternatives are compared to select the best one overall as the final remedy. The evaluation criteria are:

- Overall protection of human health and the environment
- Compliance with ARARs
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost
- State acceptance
- Community acceptance

The first two evaluation criteria (overall protection of human health and the environment, and compliance with ARARs) are considered "threshold criteria". The next five criteria (long-term effectiveness and permanence; reduction of toxicity, mobility or volume through treatment; short-term effectiveness; implementability; and, cost) are "balancing criteria" and are used to weigh major trade-offs among the alternatives. The final two criteria, referred to as "modifying criteria", are used to factor in state and community concerns and will be evaluated following public comment on the selected remedy, as described in the Proposed Plan.

The extent to which alternatives are evaluated depends on the available data and the number and types of alternatives analyzed. The detailed analysis includes total present worth of the alternatives, consisting of capital costs and operation, maintenance, and monitoring costs. The detailed analyses and costs are described below.

3.9.1.1 Threshold Criteria

Threshold criteria are standards an alternative must meet to be eligible for selection as a remedial action. There is little flexibility in meeting the threshold criteria – the alternative must meet them or it is unacceptable.

Overall Protection of Human Health and the Environment. Protectiveness is the main requirement that remedial actions must meet under CERCLA. It is an assessment of whether each alternative achieves and maintains adequate protection of human health and the environment. A remedy is protective if it eliminates, reduces, or controls current and potential risks posed by the site through each exposure pathway.

Compliance with ARARs. Compliance with ARARs is a statutory requirement of remedy selection. This criterion is used to determine whether the selected alternative would meet the federal, state, and local ARARs identified above. The compliance of each alternative with chemical-, location-, and action-specific ARARs is discussed. Section 3.1 contains a discussion of potential ARARs for the former Hanley Area.

3.9.1.2 Balancing Criteria

Balancing criteria are used to weigh tradeoffs among alternatives. They represent the standards upon which the detailed evaluation and comparative analysis of alternatives are based. A high rating on one balancing criterion generally can offset a low rating on another.

Long-Term Effectiveness and Permanence. Long-term effectiveness and permanence reflect CERCLA's emphasis on remedies that will protect human health and the environment in the long term. Under this criterion, results of a remedial alternative are evaluated in terms of the risk remaining at the site after response objectives are met. The primary focus of the evaluation is the extent and effectiveness of the actions or controls that may be required to manage the risk posed by treatment residuals or untreated wastes.

Factors to be considered and addressed are magnitude of residual risk, adequacy of controls, and reliability of controls. Magnitude of residual risk is the assessment of the risk remaining from untreated waste or treatment residuals after remediation. Adequacy and reliability of controls is the evaluation of the controls that can be used to manage treatment residuals or untreated wastes that remain at a site.

Reduction of Toxicity, Mobility, or Volume through Treatment. This criterion addresses the statutory preference for remedies that employ treatment to reduce the toxicity, mobility, or volume of the hazardous substances. That preference is satisfied when treatment is used to reduce the principal threats at a site significantly by destroying toxic chemicals or reducing the total mass or total volume of affected media. This criterion is specific to evaluating only how the treatment reduces the toxicity, mobility, and volume. It does not pertain to containment actions, such as capping.

Short-Term Effectiveness. This criterion addresses short-term impacts of the remedial alternatives by examining the effectiveness of alternatives in protecting human health and the environment during construction and implementation.

Implementability. The technical and administrative feasibility of executing an alternative and the availability of services and materials required during its implementation must be considered.

Cost. For the detailed cost analysis of alternatives, the expenditures required to complete each measure are estimated in terms of both capital and annual O&M costs. Given these values, a present-worth calculation for each alternative can be calculated for comparison. The cost estimates in this section provide an accuracy of –30 percent to +50 percent. Costs are projected for a period of 50 years in accordance with *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA 540-R-00-002; July 2000).

3.9.1.3 Modifying Criteria

Modifying criteria are used to modify the selection of the recommended alternative.

State Acceptance. This criterion pertains to the technical and administrative issues and concerns the state may have regarding the alternatives. MDNR's comments on the FS report and also on the Proposed Plan will factor into state acceptance of the recommended alternative.

Community Acceptance. This criterion pertains to the issues and concerns the public may have regarding the alternatives. It is not addressed in this report but will be addressed upon receipt of comments on the Proposed Plan and documented in the remedy decision document.

3.9.2 Remedial Alternatives Evaluation

Table 3-12 discusses each alternative with respect to the criteria for groundwater.

3.10 Comparative Analysis of Remedial Alternatives

Following the detailed analysis of the retained remedial alternatives, it was necessary to compare how well each alternative satisfied the evaluation criteria. Table 3-13 summarizes the comparative analysis results for remedial alternatives.

TABLE 3-1
Potential ARARs and To Be Considered Criteria for Remediation
Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Requirement	Requirement Synopsis
Potential Action-Specific ARARs	
Federal	
Clean Air Act (42 U.S.C. 7401 et seq.)	The Clean Air Act is intended to protect the quality of air and promote public health. Title I of the Act directed the USEPA to publish national ambient air quality standards for "criteria pollutants." In addition, USEPA has provided national emission standards for hazardous air pollutants under Title III of the Clean Air Act. Hazardous air pollutants are also designated hazardous substances under CERCLA. The Clean Air Act amendments of 1990 greatly expanded the role of National Emission Standards for Hazardous Air Pollutants by designating 179 new hazardous air pollutants and directed USEPA to attain maximum achievable control technology standards for emission sources. Such emission standards are potential ARARs if selected remedial technologies (such as incinerators or air strippers) produce air emissions of regulated hazardous air pollutants. Substantive criteria promulgated pursuant to the Clean Air Act may be considered an ARAR for remedies that involve creation of air emissions, such as excavation activities that might create dust or treatment systems that might emit VOCs.
Resource Conservation and Recovery Act (RCRA) (42 U.S.C. 321 et seq.)	RCRA was passed in 1976. It amended the Solid Waste Disposal Act by including provisions for hazardous waste management. The goals of RCRA are to promote conservation of natural resources while protecting human health and the environment. The statute sets out to control the management of hazardous waste from inception to ultimate disposal. RCRA is linked closely with CERCLA, and the CERCLA list of hazardous substances includes all RCRA hazardous wastes. The Act applies only if soils are considered a hazardous waste. Soils are required to be managed as hazardous waste if they contain listed hazardous waste or have the characteristics of hazardous waste.
State	
Missouri Air Conservation Law	The Air Conservation Law in its present form was passed in 1986. It assigned the Missouri Air Conservation Commission to the authority of the MDNR's Air and Land Protection Division. The law is an ARAR for remedies that involve creation of air emissions, such as excavation activities that have the potential to create dust.
Potential Chemical-Specific ARARs	
State	
Departmental Missouri Risk-Based Corrective Action (MRBCA) Technical Guidance (April 2006)	The guidance is to provide a framework for cleanup decisions that facilitate the constructive use of contaminated sites by protecting human health and the environment in the context of current and future site use. This guidance applies to contaminated or potentially contaminated sites and provides a methodology to conduct site-specific characterization; calculate risk-based levels protective of human health, public welfare and the environment; and implement appropriate risk management activities including long-term stewardship requirements. The guidance document provides a tool for developing cleanup levels. It is a requirement "to be considered" because it is a state guidance document rather than a promulgated requirement.

TABLE 3-2
Arsenic and Arochlor 1260 Soil PRGs
Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Chemical	From HHRA: Adult			Preliminary Remediation Goal: Adult		From HHRA: Child			Preliminary Remediation Goal: Child		Calculated PRG	Final PRG
	Concentration in Area B	ELCR Area B	HQ Area B	Cancer (ELCR = 1×10^{-5})	Noncancer (HQ = 1)	Concentration in Area B	ELCR Area B	HQ Area B	Cancer (ELCR = 1×10^{-5})	Noncancer (HQ = 1)		
Resident												
Arsenic	16	4E-05	0.08	4.00E+00	2.00E+02	16	4E-05	0.74	4.00E+00	2.16E+01	4[a]	12.3
Aroclor 1260	not assessed	—	—	1[b]	—	not assessed	—	—	1[b]	—	1	1

Note: Concentrations presented in milligrams per kilogram.
[a] Defaults to background if background is higher
[b] For a "high occupancy area" (EPA 2005).
ELCR = excess lifetime cancer risk
HHRA = human health risk assessment
HQ = hazard quotient
PRGs = preliminary remediation goals
EPA 2005 = *Polychlorinated Biphenyl (PCB) Site Revitalization Guidance Under the Toxic Substances Control Act (TSCA),* November 2005.

TABLE 3-3

Groundwater PRGs: Construction Worker Dermal Contact with Excavation Water

Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Chemical	From HHRA: ELCR	From HHRA: HQ	PRG: Cancer (ELCR = 1 × 10-5)	PRG: Noncancer (HI = 1)
Carbon tetrachloride	3.33111E-08	0.31248694	3.00E+02	3.20E+00
Tetrachloroethene	3.01015E-07	0.047585869	3.32E+01	2.10E+01

Note: PRGs presented in milligrams per liter.

ELCR = excess lifetime cancer risk

HHRA = human health risk assessment

HI = hazard index

HQ = hazard quotient

PRG = Preliminary Remediation Goal

TABLE 3-4
Calculation of Groundwater PRGs: Construction Worker Dermal Contact with Excavation Water
Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Carcinogenic PRG

$$= \frac{TR \times BW \times AT_c \times 365 \times 1000}{SF_d \times SA_{gw} \times EV_{gw} \times Z \times EF \times ED}$$

Noncarcinogenic PRG

$$= \frac{THQ \times BW \times AT_{nc} \times 365 \times 1000 \times RfD_d}{SA_{gw} \times EV_{gw} \times Z \times EF \times ED}$$

For organic Chemicals:

$$\text{If } t_{event} \leq t^*, \text{ then } Z = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{event}}{\pi}}$$

$$\text{If } t_{event} > t^*, \text{ then } Z = FA \times K_p \left[\frac{t_{event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$$

Where:

Symbol	Parameter	Unit	Value
PRG	Preliminary Remediation Goal for dermal contact with groundwater	mg/L	Chemical specific
TR	Target risk for the increased chance of developing cancer over a lifetime due to expo:	Unitless	1×10^{-6}
THQ	Target hazard quotient for individual constituents	Unitless	1
BW	Body weight	kg	70
ATc	Averaging time for carcinogens	year	70
ATnc	Averaging time for noncarcinogens	year	0.082
SAgw	Skin surface area available for contact with water	cm^2	3300
EVgw	Event frequency	event/day	1
ED	Exposure duration	year	1
EF	Exposure frequency	day/year	30
RfDd	Chemical specific dermal reference dose	mg/kg-day	Chemical specific
SFd	Chemical specific dermal cancer slope or potency factor	$(mg/kg\text{-}day)^{-1}$	Chemical specific
365	Converts ATc, ATnc in years to days	days	365
1000	Conversion factor from cm^3 to Liters	cm^3	1000
t_{event}	Event duration	hour/event	2
t^*	Time to reach steadystate	hour	Chemical specific
Z	Dermal factor	cm/event	Chemical specific
Kp	Dermal permeability coefficient	cm/hour	Chemical specific
FA	Fraction absorbed in water	Unitless	Chemical specific
τ_{event}	Lag time	hour/event	Chemical specific
B	Relative contribution of permeability coefficient	Unitless	Chemical specific

Chemical Specific Parameters

Constituent	RfDd	SFd	Time to Reach Steady State	Dermal Permeability Coefficient	Fraction Absorbed in Water	Lag Time	Relative Permeability Coefficient	Carcinogenic PRG	Noncarcinogenic PRG
Carbon tetrachloride	7.0E-04	1.3E-01	1.86E+00	1.60E-02	1.00E+00	7.76E-01	7.88E-02	3.00E+01	3.20E+00
Tetrachloroethene	1.0E-02	5.4E-01	2.18E+00	3.30E-02	1.00E+00	9.06E-01	1.66E-01	3.32E+00	2.10E+01

TABLE 3-5
Volatile Organic Compound Soil PRGs
Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Chemical Name	CAS No.	SSL DAF = 1 [mg/kg]	SSL DAF = 20 [mg/kg]	Exceeds Csat? (Y/N)	Theoretical Soil Saturation Limit (Csat) [mg/kg]	Target Leachate Concentration DAF = 20 [mg/L]"	Target Leachate Concentration DAF = 1 [mg/L]"	Construction Worker Direct Contact PRG [mg/L]	Dimensionless Henry's Constant (H') [unitless]	Soil-Water Partitioning Coefficient (K_d) [cm3/g]	Soil-Organic Carbon Partitioning Coefficient (K_{oc}) [L/kg]	Solubility (S) [mg/L]	Final PRG
Carbon tetrachloride	56-23-5	1.185	23.706	NO	2.94E+02	6.40E+01	3.20E+00	3.20E+00	1.10E+00	9.73E-02	4.86E+01	7.93E+02	1.19
Tetrachloroethene	127-18-4	9.141	182.817	NO	5.58E+02	4.20E+02	2.10E+01	2.10E+01	7.20E-01	2.14E-01	1.07E+02	2.06E+02	9.14

DAF = Dilution Attenuation Factor

SSL = Soil Screening Level

PRG = Preliminary Remediation Goal

TABLE 3-6

Soil Screening Level Partitioning Equation for Migration to Groundwater

Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Governing Equation:

$$SSL(mg/kg) = C_W \left[K_d + \frac{(\theta_W + \theta_a H')}{\rho_b} \right]$$

where,

SSL	soil screening level (mg/kg)
C_W	target soil leachate concentration, equal to the groundwatger protection standard multiplied by the dilution factor (mg/L)
K_d	soil-water partition coefficient (L/kg)
θ_W	water-filled porosity (L_{water}/L_{soil})
θ_a	air-filled soil porosity (L_{air}/L_{soil})
ρ_b	dry soil bulk density (kg/L)
n	soil porosity (L_{pore}/L_{soil})
ρ_s	soil particle density (kg/L)
H'	dimensionless Henry's constant

Variable	Value[b]	Definition
f_{oc}	*0.002*	fraction organic carbon in soil (g/g)
θ_W	*0.195*	water-filled porosity (L_{water}/L_{soil})
ρ_b	*1.570*	dry soil bulk density (kg/L)
ρ_s	*2.650*	soil particle density (kg/L)
n	*0.41*	soil porosity (L_{pore}/L_{soil})
θ_a	*0.21*	air-filled soil porosity (L_{air}/L_{soil})
pH	*7.000*	soil pH

Source: EPA (1996). Superfund Soil Screening Guidance: User's Guide. Pub No. 9355.4-23 (second edition), page 29.

TABLE 3-7

Site-Specific Dilution Attenuation Factor Calculation

Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Equation:

$$\boxed{DAF = 1 + \frac{Kid}{IL}}$$

Where:

DAF	1	dilution factor (unitless)
K	3.21E-01	aquifer hydraulic conductivity (ft/yr)
i	0.0500	lateral hydraulic gradient (unitless)
d	20.00	mixing zone depth (ft)
I	0.06	infiltration through affected soils (ft/yr)
L	150	source length parallel to groundwater flow (ft)

Infiltration estimate: I = 0.00018(P^2)

Where:

I	1.77	estimate of infiltration rate based on soil type and rainfall (cm/yr)
I	0.06	estimate of infiltration rate based on soil type and rainfall (ft/yr)
I	0.70	in/yr
I	0.00016	ft/d
P	99.06	precipitation (cm/yr)
P	39	precipitation (in/yr)
T	1.76E-02	ft^2/d
K	8.80E-04	ft/d
K	2.68E-04	m/d
K	9.79E-02	m/yr

Mixing Zone Thickness

$$\boxed{d = \left(0.0112L^2\right)^{0.5} + d_a\left(1 - \exp\left[\frac{-LI}{Kid_a}\right]\right)}$$

d	20.00	mixing zone depth (ft)
L	150	source length parallel to groundwater flow (ft)
da	20	water bearing unit thickness (ft)
I	0.06	estimate of infiltration rate based on soil type and rainfall (cm/yr)
K	3.21E-01	aquifer hydraulic conductivity (ft/yr)
i	0.05	lateral hydraulic gradient (unitless)

TABLE 3-8
General Response Actions
Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

GRA	Approach to Achieving the RAOs
No action	A baseline alternative will be evaluated because it is required by CERCLA, but taking no action will not achieve the RAOs.
Institutional Controls	Restricts access to groundwater and notifies future receptors of contamination to render the human contact pathway incomplete at the site. Institutional control process options may include deed restrictions and/or permits. Institutional controls would not satisfy the RAOs. ICs are already in place per the St. Louis Ordinance 66777, which prohibits the installation of potable water supply wells. Additional controls will not be evaluated further, since the Department of Defense does not intend to place deed restrictions on properties, such as the former Hanley Area, that may be transferred from Department ownership in the near future.
Monitoring	Establishes a program with appropriately identified locations to monitor COC concentrations, degradation, and migration. Monitoring does not achieve the RAOs as a stand-alone GRA. However, monitoring may be used in conjunction with other GRAs to satisfy the RAOs.
Containment	Includes prevention of contaminant migration offsite. Examples of containment include slurry walls, grout curtains, sheet pilings, etc. Groundwater containment options will not reduce contaminant mass and must be combined with other GRAs to address risk. Given the minimal extent of the plume and slow groundwater and contaminant migration, further containment of the plume does little to reduce risk. Therefore, containment will not be evaluated further.
In situ treatment	Involves treating contaminants in the original source area without removing the groundwater or saturated soil. In situ treatment typically is used in conjunction with monitoring for groundwater downgradient of the original source area. In situ treatments include chemical oxidation, chemical reduction, permeable reactive barriers, air sparging, steam flushing, enhanced bioremediation, anaerobic bioremediation, natural attenuation, thermal conduction heating, electrical resistance heating, and phytoremediation. In situ treatment would satisfy the RAOs.
Collection and ex situ treatment	Involves removing the groundwater followed by treatment or removal of contaminants. Ex situ treatments include chemical oxidation, air stripping, and carbon adsorption. Collection of groundwater to remove the contaminants exceeding the PRGs would require multiple pore volume flushes and is not as effective as in situ treatment technologies. Pump and treat systems result in long periods of O&M requirements. In addition, removal of groundwater is infeasible, considering the subsurface formation (e.g., low yielding clay). As a result, groundwater collection and ex situ treatment will not be evaluated further.
Removal	Removes COCs from the site and will achieve the RAOs. Therefore, removal will be evaluated further.
Disposal	Disposal involves excavating saturated soil in the area (or parts thereof) of groundwater and saturated soil contamination and disposing of the soil offsite at a licensed landfill. Disposal will be retained for screening.
Discharge	Includes discharging treated groundwater to surface water or to groundwater by reinjection. Discharge is not needed because collection of groundwater is infeasible.

TABLE 3-9
Groundwater Technology and Process Option Screening
Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Remedial Technology	Process Options	Descriptions	Treated Compounds	Limitations	Effectiveness	Implementability	Relative Cost Range	Screening Comment
No Action								
None	None	No action.	None.	No action does not achieve RAOs.	None.	Implementable.	Low.	Required by CERCLA for comparison.
Monitoring								
Monitoring	Groundwater Monitoring	Short- or long-term routine monitoring is implemented to record site conditions and COC concentration levels.	None.	Monitoring may need to be used in conjunction with other GRAs.	Effective as a tool to evaluate contaminant concentrations and other actions taken.	Implementable.	Low to moderate.	Critical to monitor effectiveness of in situ treatment actions and areas left untreated.
In Situ Treatment								
Chemical	Chemical Oxidation	Aqueous injection of oxidizing agents (peroxide/iron, permanganate, or ozone) to promote abiotic in situ oxidation of cVOCs.	Effective on most cVOCs and petroleum products.	Unproductive oxidant consumption by natural media. Injection of aqueous phase reagents is significantly constrained in low permeability media. Often requires multiple injections due to limited sweep efficiency. However, injection using pneumatic fracturing or soil mixing using trenching machinery or large augers can be implemented in low permeability media.	Effectiveness can vary from marginal to highly effective, depending on site conditions. Requires good contact between contaminant and reagent before the life span of the oxidant is spent.	Easily implemented when access to site is good. Can be implemented using conventional monitoring wells or direct push-technology methods.	Moderate to high. Oxidation not cost-effective on dilute dissolved VOC plumes. More cost-effective for high concentration source zones.	Retained for further evaluation because of effectiveness in fine-grained media would require fracturing or soil mixing. However, chemical oxidants generally have a shorter lifespan when compared to chemical reducing agents, thereby limiting the effectiveness.
	Chemical Reduction	Injection of reducing agents ZVI, hydrogen) to promote abiotic in situ reduction of cVOC.	Effective on most cVOCs.	Injection of aqueous phase reagents will be significantly constrained in low permeability media. However, injection using pneumatic fracturing or soil mixing using trenching machinery or large augers can be implemented in low permeability media.	Effective when good distribution and contact between the COCs and ZVI is achieved. Life of treatment media and need/method of media replacement a key issue.	Implementable as a whole plume, partial plume, or source zone treatment technology. Implementable where access is available. Presence of buildings or extensive underground utilities may limit implementability.	Moderate to high. More cost-effective when applied as source zone treatment or as barrier to prevent plume migration.	Retained for further evaluation because of effectiveness in fine-grained media would require fracturing or soil mixing.
	Permeable Reactive Barriers (Passive Treatment Walls)	Permeable treatment wall consisting of ZVI would be installed across the flow path of the cVOC plume. As groundwater moves through the treatment wall, cVOCs are reductively dechlorinated.	Effective on most cVOCs. Not effective on aromatics or most fuel hydrocarbons.	May lose reactive capacity, requiring replacement of the reactive medium. Permeability may decrease because of biological activity or chemical precipitation.	Effective in treating cVOCs in groundwater passing through. Does not affect upgradient groundwater.	Implementable to the needed depth of 25 to 30 feet using continuous trenching machine. Must have good access. Presence of structures or underground utilities may limit implementability.	Capital costs are moderate to high. O&M costs are low.	Not retained for whole plume treatment because the original source area would not be treated using this technology; only the plume emanating from the original source area. Barriers have high capital cost compared to other in situ technologies. Slow cVOC and groundwater migration rate in low permeability soils make this technology relatively ineffective for plume remediation because of the length of time. The barrier may need to be recharged throughout the life of the barrier.
Physical	In-Well Air Stripping (Circulating Wells)	Groundwater and saturated soil is aerated and lifted within a well bore, re-infiltrates a different strata of the formation, and creates groundwater circulation.	Effective on cVOCs. Air strippers generally are more effective at sites with high concentrations of dissolved contaminants with high Henry's law constants.	Only suitable for medium to coarse grained aquifers. Infiltrating precipitation containing oxidized constituents may foul the system.	Ineffective in low permeability environments because sufficient groundwater flow to create an effective recirculation cell is not present.	Requires adequate access for drill rig.	Moderate to high.	Not retained because of poor effectiveness in fine-grained aquifers.

TABLE 3-9
Groundwater Technology and Process Option Screening
Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Remedial Technology	Process Options	Descriptions	Treated Compounds	Limitations	Effectiveness	Implementability	Relative Cost Range	Screening Comment
	Air Sparging	Air is injected into saturated zone to remove VOCs through volatilization. May also be used at lower air flow rates to promote biodegradation of petroleum VOCs. Often coupled with SVE for collection/treatment of displaced VOCs.	Effective on cVOCs and petroleum products.	Shallow, tight aquifers may limit process effectiveness.	Ineffective in low permeability environments because the tight soil formation will prohibit air flow.	Requires adequate access for drill rig	Moderate.	Not retained because of poor effectiveness in fine-grained aquifers.
	Dual Phase Extraction	Dual phase extraction uses a high vacuum system to remove liquid (such as contaminated groundwater, NAPL) and soil vapor. It removes contaminants from above and below the water table. Once above ground, the extracted vapors, liquid-phase organics, or groundwater are separated and treated. Systems may be designed to recover only product, mixed product and water, or separate streams of product and water.	Effective on cVOCs and petroleum products.	Dual phase extraction is more effective than SVE for heterogeneous clays and fine sands. However, it is not recommended for lower permeability formations because of limited radius of influence. Infiltrating precipitation containing oxidized constituents may foul the system.	Ineffective in low permeability environments because the tight soil formation will prohibit groundwater flow.	Requires adequate access for drill rig plus groundwater recovery equipment and piping.	Moderate to high. Extensive system capital investment required relative to alternatives.	Not retained because of poor effectiveness in fine-grained aquifers.
	Hot Water or Steam Flushing/Stripping (Hydrous Pyrolysis/ Oxidation)	Steam (and possibly oxygen) is forced into an aquifer through injection wells. Vaporized components rise to the unsaturated zone, where they are removed by vacuum extraction and treated. Heating options include hot water injection, steam injection, in situ heating by six phase heating, radio frequency, etc.	Targets petroleum product treatment. cVOCs can be treated by this technology, but there are more cost-effective processes for sites contaminated with cVOCs.	The system can be clogged by small particles, microorganisms destroyed by steam, or from the increase in carbonates and silicates in the extracted liquids because of high temperatures. The process uses a large amount of energy for steam production	Ineffective in low permeability environments because the tight soil formation will prohibit air or steam flow.	Requires adequate access for drill rig plus groundwater recovery equipment and piping.	High. Costs are higher than conventional SVE because of heating equipment and power requirements. Costs are higher in saturated zone.	Not retained because of poor effectiveness in fine-grained aquifers.
	Dynamic Underground Stripping	A combination of in situ steam injection, electrical resistance heating and fluid extraction to enhance contaminant removal from the subsurface.	Laboratory tests have been successful for a variety of VOCs.	The process uses a large amount of energy. Steam adds significant amounts of water to the subsurface. Precautions must be taken so as not to mobilize contaminants past the capture zones. There has been some concern that dynamic underground stripping will sterilize the subsurface so that microorganisms will not attack the contaminants. The treatment units can foul because of microorganisms that are destroyed by steam. Small particles that are pumped to the surface can also clog the system, and high temperatures increase carbonates and silicates in the extracted liquids.	Ineffective in low permeability environments because the tight soil formation will prohibit steam and groundwater flow.	Requires adequate access for drill rig plus groundwater recovery equipment and piping.	Relatively extensive capital system requirements, but becomes more cost-effective in larger applications. Considerable uncertainly in actual full-scale application.	Not retained because of poor effectiveness in fine-grained aquifers and small scale of this application.

TABLE 3-9
Groundwater Technology and Process Option Screening
Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Remedial Technology	Process Options	Descriptions	Treated Compounds	Limitations	Effectiveness	Implementability	Relative Cost Range	Screening Comment
Biological	Cometabolic Bioremediation	Injection of dilute solution containing inducers to enhance cometabolic breakdown. Inducers serve as carbon sources that activate aerobic enzyme systems know to degrade cVOCs (fortuitous cometabolism). Options of methane, ammonia, toluene, or phenol as inducers.	Target compounds are tetrachloroethene and TCE. The addition of methane or methanol has been demonstrated to degrade cVOCs. Toluene, propane, and butane also have been used to support the cometabolism of TCE.	Regulatory approval for use of specific cometabolites may be required. Higher permeability zones are cleaned up much faster because groundwater flow rates are greater. Limited effectiveness for dichloroethene. Requires significant process control.	Considerable uncertainty on rate and extent of biodegradation that can be achieved, particularly in low permeability soils.	Requires site-specific bench- or pilot-scale testing. Requires adequate access for drill rig plus delivery of substrate and oxygen.	High. The cost to operate and maintain can be significant because a continuous source of methane or other inducer solution must be delivered to the contaminated groundwater.	Not retained because of relatively high cost and poor effectiveness in low permeability soils.
	Enhanced Anaerobic Bioremediation	Subsurface delivery of substrates (lactate, vegetable oil, molasses etc.) that serve as electron donors within the target zone to stimulate anaerobic biodegradation of cVOCs by reductive dechlorination.	Target compounds are cVOCs.	Requires time and multiple applications of substrate to achieve preliminary remediation goals (PRGs). More difficult, although not impossible, to implement in fine-grained aquifer.	Effectiveness demonstrated on numerous sites given good distribution of substrate, but may be limited in low permeability environment.	Implementable either as a grid-based or curtain-based injection system.	Cost is moderate to high.	Not retained because of time required to reduce concentrations to PRGs and presence of fine-grained media aquifer. In addition, there is not significant amount of reductive dechlorination occurring.
	Monitored Natural Attenuation	Short- or long-term routine monitoring is implemented to record site conditions, concentration levels, and natural attenuation parameters. Natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials are allowed to reduce concentrations to acceptable levels.	Target contaminants for natural attenuation are VOCs.	Data used as input parameters for modeling need to be collected. Activities and Use Limitations may be required, and the site may not be available for reuse until contaminant levels are reduced.	Site natural attenuation data indicate conditions are conducive to reductive dechlorination.	Implementable.	Low.	Not retained because of time required to reduce concentrations to PRGs.
	Phytoremediation	Phytoremediation is a set of processes that uses plants to remove, transfer, stabilize, and destroy organic and inorganic contamination in groundwater, surface water, and leachate. These mechanisms include enhanced rhizosphere biodegradation, hydraulic control, phytodegradation and phytovolatilization.	Phytoremediation may be applicable for the remediation of cVOCs. Poplar trees have been used for TCE.	Toxicity and bioavailability of biodegradation products is not always known. Degradation byproducts may be mobilized in groundwater or bioaccumulated in animals. More research is needed to determine the fate of various compounds in the plant metabolic cycle. Climatic or seasonal conditions may interfere or inhibit plant growth, slow remediation efforts, or increase the length of the treatment period. It can transfer contamination across media (from soil to air, for example). Phytoremediation likely will require a large land area. Phytoremediation for extraction or degradation generally is limited to relatively shallow depths of root penetration.	Not effective at the site because depth to groundwater contamination is beyond the depths effected by plant roots.	Not implementable because the dissolved phase groundwater plume is beyond plant root penetration.	Low to moderate costs depending on type of application.	Not retained because cVOC-contaminated groundwater is located more than 13 feet below ground.
Thermal	TCH or ERH	Soils and groundwater are heated in situ to target temperatures to volatilize water and organic contaminants.	VOCs and fuels may be treated.	Difficult to implement beneath structures or where extensive underground utilities are present or in aquifers with very high groundwater flow rates (such as karst conditions).	Highly effective in removing VOCs from the subsurface.	Requires adequate access for drill rig plus above ground process equipment.	Medium to high	Retained for further evaluation.

TABLE 3-9
Groundwater Technology and Process Option Screening
Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Remedial Technology	Process Options	Descriptions	Treated Compounds	Limitations	Effectiveness	Implementability	Relative Cost Range	Screening Comment
Removal								
Excavation	Excavation	Excavation of groundwater and saturated soil exceeding PRGs can use ordinary construction equipment such as backhoes, bulldozers, and front-end loaders.	Excavation is applicable to the full range of contaminant groups with no particular target group.	Fugitive emissions such as dust and particulates are often a problem during operations. Communities often oppose the transportation of excavated material through populated areas. Limited to depths achievable with conventional excavation equipment.	Highly effective because VOCs are removed and soil and groundwater can be easily sampled during excavation to verify that PRGs are met.	Implementable using conventionally available technology. Presence of extensive underground utilities may limit implementability in some areas.	Moderate to high. Costs increase with the depth.	Retained for further evaluation.
Disposal								
Landfill	Resource Conservation and Recovery Act (RCRA) Landfill	Solid hazardous wastes are permanently disposed of in a RCRA-permitted landfill.	Disposal in a RCRA-permitted landfill is applicable to hazardous wastes.	Disposal options may be limited due to mixed waste.	Effective.	Readily implementable.	High because of classification of waste and proximity to a RCRA-permitted landfill. Disposal rates are high.	Retained for further evaluation.
	Non-RCRA Landfill	Solid nonhazardous wastes are permanently disposed of in a non-Subtitle D landfill.	Disposal in a Subtitle D landfill for special waste.	Disposal options may be limited due to mixed waste.	Effective.	Readily implementable.	Low to moderate because of proximity to a Subtitle D landfill.	Retained for further evaluation.

Note: Highlighted technologies are not retained for further consideration in the development of remedial alternatives.

Effectiveness is the ability to perform as part of an overall alternative that can meet the RAOs under conditions and limitations that exist onsite.

Implementability is the likelihood that the process could be implemented under the physical, regulatory, technical, and schedule constraints.

Relative cost is for comparative purposes only and it is judged relative to the other processes and technologies that perform similar functions.

TABLE 3-10
Calculation Input Values for Groundwater Screening Levels: Resident Exposure through Potable Use
Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Ingestion and Inhalation Exposure

Variable	Value
Target cancer risk (TR), unitless	0.00001
Target hazard quotient (THQ), unitless	1
Averaging time (AT), days	365
Exposure frequency (EF), days	350
Exposure duration (ED), years	30
Mutagenic Exposure duration (ED_{0-2}), years	2
Mutagenic Exposure duration (ED_{2-6}), years	4
Mutagenic Exposure duration (ED_{6-16}), years	10
Mutagenic Exposure duration (ED_{16-30})m years	14
Life Time (LT)	70
Exposure Time (ET) hours/day	24
Body Weight - adult (BW_a), kg	70
Body Weight - children 1–6 yr (BW_c), kg	15
Exposure duration - child (ED_c), years	6
Water Ingestion - adult (IRW_a), L/day	2
Water Ingestion - child (IRW_c), L/day	1
Volatilization factor of Andelman (K), L/m^3	0.5
Ingestion Factor - L-year/kg-day	1.085714286
Mutagenic Ingestion Factor - L-year/kg-day	3.390476191

TABLE 3-11

Groundwater Screening Levels: Resident Exposure through Potable Use

Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Toxicity Values Used

Chemical	CAS Number	Ingestion SF $(mg/kg\text{-}day)^{-1}$	SFO Ref	Inhalation Unit Risk $(\mu g/m^3)^{-1}$	IUR Ref	Chronic RfD (mg/kg-day)	RfD Ref	Chronic RfC (mg/m^3)	RfC Ref	MCL µg/L
Chloroform	67-66-3	3.10E-02	CALEPA	2.30E-05	IRIS	1.00E-02	IRIS	9.77E-02	ATSDR	-
Naphthalene	91-20-3	-		-	-	2.00E-02	IRIS	3.00E-03	IRIS	-
Tetrachloroethane, 1,1,1,2-	630-20-6	2.60E-02	IRIS	7.40E-06	IRIS	3.00E-02	IRIS	-		-
Tetrachloroethane, 1,1,2,2-	79-34-5	2.00E-01	IRIS	5.80E-05	IRIS	4.00E-03	PPRTV	-		-

Preliminary Remediation Goals

Chemical	Ingestion TR = 1.0E-5 (µg/L)	Inhalation TR = 1.0E-5 (µg/L)	Carcinogenic TR = 1.0E-5 (µg/L)	Ingestion HQ = 1 (µg/L)	Inhalation HQ = 1 (µg/L)	Noncarcinogenic HI = 1 (µg/L)	Final PRG (µg/L)
Chloroform	2.17E+01	2.12E+00	1.93E+00	3.65E+02	2.04E+02	1.31E+02	1.9
Naphthalene	-	-	-	7.30E+02	6.26E+00	6.20E+00	6.2
Tetrachloroethane, 1,1,1,2-	2.59E+01	6.58E+00	5.24E+00	1.10E+03	-	1.10E+03	5.2
Tetrachloroethane, 1,1,2,2-	3.36E+00	8.39E-01	6.71E-01	1.46E+02	-	1.46E+02	0.67

Notes:

µg/L = *micrograms per liter*
$\mu g/m^3$ = micrograms per cubic meter
mg/kg = milligrams per kilogram
CALEPA = California Environmental Protection Agency
CAS = Chemical Abstracts Service
HI = hazard index
HQ = hazard quotient
IRIS = Integrated Risk Information System
IUR = inhalation unit risk
MCL = *Maximum Contaminant Level*
PRG = Preliminary Remediation Goal
PPRTV = Peer Reviewed Toxicity Value
RfC = reference concentration
RfD = reference dose
SF = slope factor
SFO = oral carcinogenic potency slope factor
TR = target cancer risk

TABLE 3-12
Detailed Evaluation of Remedial Alternatives
Feasibility Study Report—St. Louis Ordnance Plant, former Hanley Area, St. Louis, Missouri

Evaluation Criteria	Alternative 1 No Action	Alternative 2 In Situ Groundwater Treatment Using Thermal Technologies, Soil and Powder Well Sediment Removal and Offsite Disposal	Alternative 3 In Situ Groundwater Treatment and Soil and Powder Well Sediment Removal and Offsite Disposal	Alternative 4 Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal and Offsite Disposal
Type and quantity of residuals that will remain following treatment	Not applicable.	Ultimately no treatment residuals will remain. Concentrations of VOC daughter products such as vinyl chloride may be generated, but vinyl chloride is expected to biodegrade and not accumulate. Monitoring will evaluate the residuals.	Ultimately no treatment residuals will remain. Concentrations of VOC daughter products such as vinyl chloride may be generated, but vinyl chloride is expected to biodegrade and not accumulate. Monitoring will evaluate the residuals.	Not applicable.
Statutory preference for treatment	Does not satisfy.	Meets preference for treatment.	Meets preference for treatment.	Does not satisfy.
Short-Term Effectiveness				
Protection of workers during remedial action	Not applicable.	Treatment is not expected to create additional risk to industrial workers onsite because of the proximity of workers to the TTZ. Workers implementing the remedy would have limited potential for exposure to PCE, since remediation-derived waste may be generated only as part of monitoring well installation and abandonment activities. The surface soil removal activities were based on residential exposure risk, not industrial workers. Risks associated with heavy machinery use and with intrusive activities on the environment during the remedial action will be addressed through safe work practices and a comprehensive health and safety plan.	Treatment is not expected to create additional risk to industrial workers onsite. Workers implementing the remedy would have potential exposure to PCE, since soil mixing will expose most of the PCE within the TTZ. Risk associated with surface soil removal was based on exposure of residents, not industrial workers. Risks associated with heavy machinery use and with intrusive activities on the environment during the remedial action will be addressed through safe work practices and a comprehensive health and safety plan.	Removal activities are not expected to pose additional risk to industrial workers onsite. Workers implementing the remedy could be exposed to PCE, since excavation and removal would expose the PCE within the TTZ. Risk associated with surface soil removal was based on exposure of residents, not industrial workers. Risks associated with heavy machinery use and with intrusive activities on the environment during the remedial action will be addressed through safe work practices and a comprehensive health and safety plan.

TABLE 3-12
Detailed Evaluation of Remedial Alternatives
Feasibility Study Report—St. Louis Ordnance Plant, former Hanley Area, St. Louis, Missouri

Evaluation Criteria	Alternative 1 No Action	Alternative 2 In Situ Groundwater Treatment Using Thermal Technologies, Soil and Powder Well Sediment Removal and Offsite Disposal	Alternative 3 In Situ Groundwater Treatment and Soil and Powder Well Sediment Removal and Offsite Disposal	Alternative 4 Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal and Offsite Disposal
Protection of the community during remedial action	Not applicable.	Implementation of the groundwater TTZ alternative would have little (if any) impact to the community. Excavation and removal work associated surface soil remediation may affect the community by trucks entering and leaving the site.	Implementation of the groundwater TTZ alternative would have little (if any) impact to the community. Excavation and removal work associated surface soil remediation may affect the community by trucks entering and leaving the site.	Excavation and removal work associated with surface soil and groundwater TTZ remediation may affect the community by trucks entering and leaving the site. This alternative would have more trucks entering and leaving the site.
Potential environmental impacts of remedial action	Not applicable.	Treatment would introduce minimal impacts due to construction work, such as excavation and transportation of surface soil	Treatment would introduce minimal impacts due to construction work, such as excavation and transportation of surface soil.	Treatment would introduce impacts from construction work, such as excavation and transportation of surface and subsurface soil.
Time until protection is achieved	Protection is not achieved.	Due to the existing ordinance and depth to groundwater, protection would be achieved immediately.	Due to the existing ordinance and depth to groundwater, protection would be achieved immediately.	Due to the existing ordinance and depth to groundwater, protection would be achieved immediately.
Implementability				
Technical feasibility	Not applicable.	Feasible, but complex because of thermal treatment application and its design. An additional power source would be required.	Feasible, but complex because application of the chemical reduction amendment and design would be required.	Feasible.
Reliability of technology	Not applicable.	Reliable.	Reliable.	Reliable.
Administrative feasibility	Not feasible.	Feasible.	Feasible.	Feasible.
Availability of services, equipment, and materials	Not applicable.	Additional power sources would likely be required to operate this remedial action.	Equipment and materials are readily available.	Equipment and materials are readily available.

TABLE 3-12
Detailed Evaluation of Remedial Alternatives
Feasibility Study Report—St. Louis Ordnance Plant, former Hanley Area, St. Louis, Missouri

Evaluation Criteria	Alternative 1 No Action	Alternative 2 In Situ Groundwater Treatment Using Thermal Technologies, Soil and Powder Well Sediment Removal and Offsite Disposal	Alternative 3 In Situ Groundwater Treatment and Soil and Powder Well Sediment Removal and Offsite Disposal	Alternative 4 Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal and Offsite Disposal
Cost				
Capital cost	$0	$2,741,000	$1,875,000	$2,074,000
Present worth[a]	$0	$1,985,000	$1,985,000	$1,985,000
Period of analysis (yr)	$0	50[b]	50[b]	50[b]
Capital and present worth	$0	$4,726,000[c]	$3,860,000[c]	$4,059,000[c]
Present Cost Range (-30 / +50)	$0	$3,308,000 to $7,089,000	$2,702,000 to $5,790,000	$2,841,000 to $6,089,000

[a] Present worth of periodic costs (5-year review, operation and maintenance) are shown.

[b] Based on USEPA, 2000, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA 540-R-00-002).

[c] Cost estimate is provided in Appendix A.

TABLE 3-13
Comparative Analysis Results
Feasibility Study Report—St. Louis Ordnance Plant, former Hanley Area, Missouri

Criteria	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Overall protection of human health and the environment	1	4	4	4
Compliance with ARARs	1	4	4	4
Long-term effectiveness and permanence	1	4	4	4
Reduction of toxicity, mobility, or volume through treatment	1	3	3	2
Short-term effectiveness	1	3	3	3
Implementability	4	2	3	4
Cost	4	1	3	3
Total Score	**13**	**21**	**24**	**24**

1—poor 2—satisfactory 3—good 4—excellent

LEGEND

- 2008 Soil Sample
- 2005 Soil Sample
- 2001 Soil Sample
- 1998 Soil Sample Locations
- 1991 Soil Sample
- Powder Well
- Composite Sample Portion Line
- Site Boundary
- 220 Former Building
- Estimated Excavation Limits

0 50 100 Feet

NOTES:
1. J = Reported value is estimated.
2. COC = Chemical of Concern
3. PRG = Preliminary Remediation Goal
4. The surface soil remedial action will not include areas covered with concrete.

FIGURE 3-1
SOIL REMOVAL AREAS
St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

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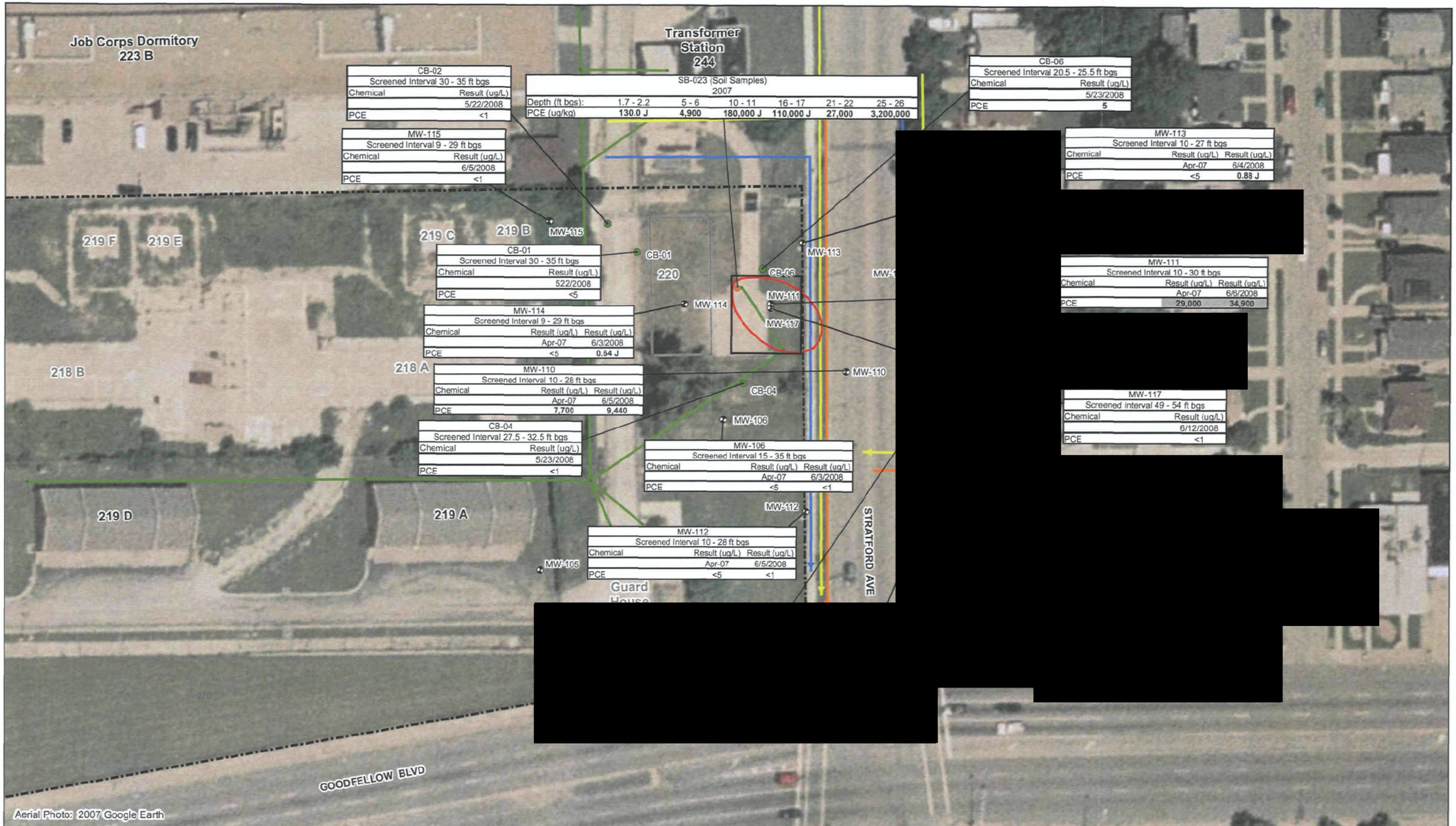
\\LACLEDE\PROJ\CONTIENVIRONMENT\364298FLWSLOP\00_PROPOSAL\FLW&SLOPS\SLOP_GIS\FILES_FROM_MIKE\MAPFILES\FS\FIG_3-1_SOIL_REMOVAL_AREAS.MXD RHURSEY 1/25/2010 10:13:31



LEGEND
- Groundwater Sample Point
- Temporary Well
- Soil Boring
- Monitoring Well

Approximate Utilities
- Natural Gas
- Sanitary Sewer
- Telephone
- Water

- Area Exceeding the Construction Worker PRG
- Target Treatment Zone/ Excavation Extents
- Former Building
- Site Boundary

NOTES:
1. The PRG is protective of construction worker exposure.
2. COC = chemical of concern
3. PCE = tetrachloroethene
4. PRG = Preliminary Remediation Goal of 21,000 µg/L for PCE
5. J = Estimated Concentration
6. < = Chemical not detected above the method detection limit
7. Bold type indicates the chemical was detected.
8. Shading indicates a detected concentration above the construction worker PRG.
9. ug/L = micrograms per liter
10. ug/kg = micrograms per kilogram

FIGURE 3-2
COCs IN GROUNDWATER AT CONCENTRATIONS EXCEEDING PRGs
St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri
CH2MHILL

\\LACLEDE\PROJ\CONTIENVIRONMENT\364298FLWSLOP\00_PROPOSAL\FLW&SLOPS\SLOP_GIS\FILES_FROM_MIKE\MAPFILES\FS\FIG_3-2_COCS_GW_EXCEEDS_PRGS.MXD RHURSEY 1/25/2010 10:10:19

4. Summary and Conclusions

The object of the feasibility study was to develop and evaluate remedial alternatives to address potential unacceptable risk to human health and to meet ARARs. As part of the evaluation, chemical- and action-specific ARARs were evaluated to develop remedial alternatives. The following RAOs were established based on regulatory requirements, standards, and guidance:

- Prevent unacceptable risk to future human receptors (both onsite and offsite) from potential vapor intrusion to indoor air.
- Prevent unacceptable risk to residents from ingestion of onsite soil containing antimony and thallium within Exposure Units E, I, J, and K.
- Prevent unacceptable risk to onsite construction workers from dermal contact with groundwater containing CT and PCE.
- Remove soil to prevent future human exposure to onsite soil with elevated concentrations of arsenic, lead, and Aroclor 1260 at the following eight historical sample locations:
  - Sample NS03A arsenic at 44 mg/kg; lead at 5,840 mg/kg
  - Sample NS08A arsenic at 67.7 mg/kg
  - Sample SS-001 Aroclor 1260 at 1.4 mg/kg
  - Sample SED-001 Aroclor 1260 at 569 mg/kg
  - Sample SS-218A-2 lead at 2,724 mg/kg
  - Sample SS-219B arsenic at 108 mg/kg
  - Sample SS-219C arsenic at 68.8 mg/kg
  - Sample SS55A Aroclor 1260 at 18,200 mg/kg
- Remove the sediment from the onsite powder wells to prevent future human exposures.

PRGs were developed for soil and groundwater based on the RAOs. GRAs are actions that will accomplish the RAOs. First GRAs were identified. Then potential remedial technologies were screened on the basis of effectiveness, implementability, and cost. Finally, four remedial alternatives were developed and assessed for each media based using the seven NCP evaluation criteria and compared in terms of ability to satisfy the criteria:

- Alternative 1—No Action
- Alternative 2—In Situ Groundwater Treatment Using Thermal Technologies, Soil and Powder Well Sediment Removal, and Offsite Disposal
- Alternative 3—In Situ Groundwater Treatment and Soil and Powder Well Sediment Removal and Offsite Disposal
- Alternative 4—Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal, and Offsite Disposal

Alternatives 2, 3, and 4 meet the threshold criteria, but Alternative 1 does not. Alternatives 2, 3, and 4 will reduce the COC mass. The preferred alternative will be presented in the Proposed Plan. In accordance with the NCP, the Proposed Plan, and other documents in the administrative record, will be released to the public for review and comment. Public input on the alternatives is paramount in the selection process. The preferred remedy may be modified based on the comments received.

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Alternative 2 - In-Situ Groundwater Treatment Using Thermal Technologies, Soil and Powder Well Sediment Removal, and Offsite Disposal
Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Unit Cost	Total	Source	Assumptions
Confirmation Sampling for Soil Removal Activities						
Laboratory Analysis						
Arsenic Analysis	48	EA	$25	$1,200	Vendor Quote	5 soil borings each at 2 removal areas for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Arsenic and Lead Analysis	24	EA	$51	$1,224	Vendor Quote	5 soil borings at 1 removal area for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Thallium Analysis	48	EA	$25	$1,200	Vendor Quote	5 soil borings each at 2 removal areas for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Lead Analysis	24	EA	$26	$624	Vendor Quote	5 soil borings at 1 removal area for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Aroclor 1260 Analysis	24	EA	$26	$624	Vendor Quote	5 soil borings at 1 removal area for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Fieldwork Expenses						
Labor	1	LS	$7,200	$7,200	Engineer's Estimate	Fieldwork, office support
Equipment	1	LS	$725	$725	Engineer's Estimate	Sampling and health and safety equipment
Travel	1	LS	$288	$288	Engineer's Estimate	Assumes 3 days to complete surface soil delineation.
Subtotal				**$13,085**		
Excavation/Backfill/Transport and Disposal of Soil and Sediment						
Site Preparation						
Preparation	1	LS	$6,540	$6,540	Engineer's Estimate	Subcontractor labor, backhoe, 10-wheel dump truck, private utility locate.
Laboratory Analysis						
Waste Characterization	7	EA	$900	$6,300	Engineer's Estimate	Characterization of soil at each removal area for offsite disposal, sample technician, equipment, and supplies.
Excavation						
Soil Excavation - Arsenic and Lead	245	CY	$70	$17,150	Engineer's Estimate	Arsenic and lead excavation dimensions: 475sf x 1', 1125sf x 2', 1210sf x 2', and 1340sf x 1'
Soil Excavation - Thallium	155	CY	$70	$10,850	Engineer's Estimate	Thallium excavation dimensions: 915sf x 2' and 1,175sf x 2'
Soil Excavation - Aroclor 1260	65	CY	$70	$4,550	Engineer's Estimate	Aroclor 1,260 excavation dimension: 875sf x 2'
IDW Management						
Transportation & Disposal-Special Waste (conversion factor 1.7)	160	TN	$72	$11,520	Engineer's Estimate	Assumes 20% of soil IDW is special waste.
Transportation & Disposal-Hazardous (conversion factor 1 7)	474	TN	$278	$131,772	Engineer's Estimate	Assumes 60% of soil IDW is hazardous.
Transportation & Disposal-Hazardous Pre-treat (conversion factor 1.7)	160	TN	$422	$67,520	Engineer's Estimate	Assumes 20% of soil IDW is hazardous requiring pre-treatment.
Restoration						
Backfill with Imported Fill (conversion factor of 1.6)	744	TN	$41	$30,504	Engineer's Estimate	Subcontractor labor, compactor, backhoe, 10-wheel dump truck.
Seeding and straw	7,115	SF	$0.15	$1,067	Engineer's Estimate	Standard grass seed.
Watering	1	LS	$22,660	$22,660	Engineer's Estimate	Daily watering for 6 weeks - includes water truck services.

Alternative 2 - In-Situ Groundwater Treatment Using Thermal Technologies, Soil and Powder Well Sediment Removal, and Offsite Disposal
Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Unit Cost	Total	Source	Assumptions
Survey Support						
Surveying of Excavation Extents	1	LS	$2,200	$2,200	Vendor Quote	Includes survey of 4 corners at 7 removal areas, data evaluation and report.
Air Monitoring						
Air Monitoring	10	DY	$29	$290	Engineer's Estimate	Breathing zone monitoring during excavation activities.
Fieldwork Expenses						
Labor	1	LS	$10,000	$10,000	Engineer's Estimate	Fieldwork and office support.
Equipment	1	LS	$300	$300	Engineer's Estimate	Sampling and health and safety equipment
Travel	1	LS	$950	$950	Engineer's Estimate	Assumes 2 weeks to complete surface soil removal and backfill.
Subtotal				**$324,173**		
Powder Well Sediment Removal						
Sediment Removal						
Sediment Removal Services	28	CY	$174	$4,872	Vendor Quote	Removal of 28 yd^3 of sediment from 22 powder wells via vacuum truck.
IDW Management						
Transportation and Disposal - Special Waste (conversion factor of 1.29 for sediment)	18	TN	$70	$1,260	Engineer's Estimate	Disposal of 36 tons of sediment as 50% as special waste.
Transportation and Disposal - Hazardous (conversion factor of 1.29 for sediment)	18	TN	$270	$4,860	Engineer's Estimate	Disposal of 36 tons of sediment as 50% hazardous.
Laboratory Analysis						
Waste Characterization	1	LS	$2,283	$2,283	Vendor Quote	
Fieldwork Expenses						
Labor	1	LS	$6,000	$6,000	Engineer's Estimate	Fieldwork, office support.
Travel Expenses	1	LS	$318	$318	Engineer's Estimate	
Equipment	1	LS	$725	$725	Engineer's Estimate	
Air Monitoring						
Air Monitoring	3	DY	$29	$87	Engineer's Estimate	Breathing zone monitoring during sediment removal activities.
Subtotal				**$19,145**		
Pre-Remedial Design Sampling						
Installation of Groundwater Sampling Points						
Drilling Services	1	LS	$9,500	$9,500	Vendor Quote	Installation of 7 temporary wells, abandonment, drums, mobilization.
Laboratory Analysis						
Analysis of COCs	11	EA	$60	$660	Vendor Quote	Analysis of PCE; includes QA/QC.
Waste Characterization	2	EA	$289	$578	Vendor Quote	
IDW Management						
Transportation and Offsite Disposal	1	LS	$1,700	$1,700	Vendor Quote	Offsite disposal of 4 soil drums. Liquid IDW discharged via sanitary sewer system.
Fieldwork Expenses						
Labor	1	LS	$7,600	$7,600	Engineer's Estimate	Fieldwork, office support, and data validation.
Equipment	1	LS	$1,375	$1,375	Engineer's Estimate	Sampling and health and safety equipment
Travel Expenses	1	LS	$318	$318	Engineer's Estimate	Assumes 3 days to complete groundwater delineation.

Alternative 2 - In-Situ Groundwater Treatment Using Thermal Technologies, Soil and Powder Well Sediment Removal, and Offsite Disposal

Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Unit Cost	Total	Source	Assumptions
Survey Support						
Survey of Sample Locations	1	LS	$1,630	$1,630	Vendor Quote	Includes survey of 7 groundwater sample points, data evaluation and report.
Subtotal				**$23,361**		
Well Abandonment / Installation						
Well Abandonment and Installation at Plumes A and C						
Abandonment and Installation Services	1	LS	$9,370	$9,370	Vendor Quote	Abandonment of 4 shallow 2" well (MW-105, MW-106, MW-114, MW-111) and 1 deep well (MW-117), and installation of 3 shallow 2" wells (2 at Plume A and 1 at Plume C); includes well development, drums, and mobilization
IDW Management						
Transportation and Offsite Disposal	1	LS	$4,400	$4,400	Vendor Quote	Offsite disposal of 12 soil drums and discharge of liquid IDW via sanitary sewer system
Fieldwork Expenses						
Labor	1	LS	$9,200	$9,200	Engineer's Estimate	Fieldwork and office support.
Equipment and Supplies	1	LS	$725	$725	Engineer's Estimate	
Travel Expenses	1	LS	$404	$404	Engineer's Estimate	Assumes 4 days to complete abandonment/installation activities.
Survey Support						
Survey of New Wells	1	LS	$1,470	$1,470	Vendor Quote	Includes survey of 3 wells, data evaluation and report.
Subtotal				**$25,569**		
Thermal Conductive Heating at Plume A						
Design and Installation						
Design and Permitting	1	LS	$85,600	$85,600	Vendor Quote	Installation and operation of 23 thermal conductive wells and 5 SVE wells at Plume A source area (45' x 45' x 30'), process equipment, power usage, transport and offsite disposal of solid IDW.
Procurement and Mobilization	1	LS	$64,000	$64,000	Vendor Quote	
Power Drop and Transformer	1	LS	$26,000	$26,000	Vendor Quote	
Drilling/Well Installation	1	LS	$111,400	$111,400	Vendor Quote	
Vapor Cover Installation	1	LS	$12,000	$12,000	Vendor Quote	
Electrical Construction	1	LS	$61,000	$61,000	Vendor Quote	
Mechanical Construction	1	LS	$52,600	$52,600	Vendor Quote	
Thermal Power Equipment	1	LS	$38,200	$38,200	Vendor Quote	
Effluent Treatment System	1	LS	$197,600	$197,600	Vendor Quote	
Commissioning	1	LS	$39,900	$39,900	Vendor Quote	
Fieldwork Expenses						
Labor	1	LS	$60,500	$60,500	Engineer's Estimate	Fieldwork and office support.
Equipment	1	LS	$3,000	$3,000	Engineer's Estimate	Sampling and health and safety equipment.
Travel	1	LS	$5,930	$5,930	Engineer's Estimate	Assumes 8 weeks to provide oversight during 160-day thermal conductive heating activities.
Operation						
Maintenance Hardware	1	LS	$23,250	$23,250	Vendor Quote	
Subcontractor Labor, Travel, Per Diem	1	LS	$103,500	$103,500	Vendor Quote	
Process Monitoring, Sampling, and Analysis	1	LS	$27,000	$27,000	Vendor Quote	
Rental and Fees	1	LS	$54,000	$54,000	Vendor Quote	
Subcontractor Demobilization and Other Costs						
Demobilization	1	LS	$46,000	$46,000	Vendor Quote	
Reporting	1	LS	$21,000	$21,000	Vendor Quote	
Power	1	LS	$101,250	$101,250	Vendor Quote	
Subtotal				**$1,133,730**		

Alternative 2 - In-Situ Groundwater Treatment Using Thermal Technologies, Soil and Powder Well Sediment Removal, and Offsite Disposal

Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Unit Cost	Total	Source	Assumptions
Groundwater Monitoring at Plume A - Year 1 through 5						
Laboratory Analysis						
Analysis of COCs	80	EA	$60	$4,800	Vendor Quote	10 monitoring wells sampled per event. Annual sampling for Years 1 through 5; includes QA/QC. Includes gauging of wells.
Waste Characterization	5	EA	$289	$1,445	Vendor Quote	
IDW Management						
Transportation and Disposal	5	EA	$1,516	$7,580	Vendor Quote	Disposal of liquid IDW via sanitary sewer system.
Fieldwork Expenses						
Labor	5	EA	$8,400	$42,000	Engineer's Estimate	Fieldwork, office support, data validation for 5 events.
Equipment and Supplies	5	EA	$808	$4,040	Engineer's Estimate	Sampling and health and safety equipment
Travel Expenses	5	EA	$318	$1,590	Engineer's Estimate	Assumes 2 days to complete groundwater sampling activities.
Subtotal				**$61,455**		
Remedial Design			6%	**$96,031**		
Work Planning			6%	**$96,031**		
Contingency			25%	**$400,130**		
Subtotal				**$592,192**		
Total Cost of Alternative 2 with Remedial Design and Contingency				**$2,192,710**		
Construction Oversight/Project Management			10%	**$219,271**		
Reporting (Includes RACR and Annual LTM Report)			15%	**$328,907**		
Subtotal				**$548,178**		
Total Cost				**$2,740,888**		
Operation and Maintenance Costs - Year 6 through 50						
Laboratory Analysis						
Analysis of COCs	16	EA	$60	$960	Vendor Quote	10 monitoring wells sampled every 5 years; includes QA/QC.
Waste Characterization	1	EA	$289	$289	Vendor Quote	
IDW Management						
Transportation and Disposal	1	LS	$1,516	$1,516	Vendor Quote	Disposal of liquid IDW via sanitary sewer system.
Fieldwork Expenses						
Labor	1	LS	$8,400	$8,400	Engineer's Estimate	Fieldwork, office support, data validation per event.
Equipment	1	LS	$808	$808	Engineer's Estimate	Sampling and health and safety equipment
Travel Expenses	1	LS	$232	$232	Engineer's Estimate	Assumes 2 days to complete groundwater sampling activities.
Reporting						
Groundwater Monitoring and Inspection Report	1	LS	$12,000	$12,000	Engineer's Estimate	
Data Management	1	LS	$2,400	$2,400	Engineer's Estimate	
Subtotal				**$26,605**		
Contingency			30%	**$7,982**		
Subtotal				**$34,587**		
Project Management			10%	**$3,459**		
Technical Support			20%	**$6,917**		
Subtotal				**$10,376**		
Total Operation and Maintenance Costs Per Event				**$44,962**		
Periodic Costs - Year 6 through 50						
5-year Review	LS	1	**$15,000**	$15,000	Engineer's Estimate	
Periodic Costs Per 5-year Review				**$15,000**		

Alternative 2 - In-Situ Groundwater Treatment Using Thermal Technologies, Soil and Powder Well Sediment Removal, and Offsite Disposal

Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Unit Cost	Total	Source	Assumptions
Total O&M and 5-year Review				**$59,962**		
			2.7%	Discount Rate		
			0.0%	Inflation Rate		
Present Value Analysis						
Present Worth Cost of Five-Year Review O&M Cost			27.2621	$1,675,392		
Present Worth of Periodic Costs in Year 5			0.8753	$52,484		
Present Worth of Periodic Costs in Year 10			0.7661	$45,938		
Present Worth of Periodic Costs in Year 15			0.6706	$40,209		
Present Worth of Periodic Costs in Year 20			0.5869	$35,194		
Present Worth of Periodic Costs in Year 25			0.5137	$30,805		
Present Worth of Periodic Costs in Year 30			0.4497	$26,963		
Present Worth of Periodic Costs in Year 35			0.3936	$23,600		
Present Worth of Periodic Costs in Year 40			0.3445	$20,657		
Present Worth of Periodic Costs in Year 45			0.3015	$18,080		
Present Worth of Periodic Costs in Year 50			0.2639	$15,825		
Total Present Worth Costs				**$1,985,148**		
TOTAL CAPITAL AND PRESENT WORTH COSTS				**$4,726,036**		

Note:

1) The estimate above is considered budgetary-level cost estimating, suitable for use in project evaluation and planning. Actual construction costs are expected to vary from these estimates due to market conditions, actual costs of purchased materials, quantity variations, regulatory requirements, and other factors existing at the time of construction.

2) Costs were based on RS Means (2005 edition using a 4% annual increase to 2010), MRK Exploration quote, Environmental Works quote, Terra Therm quote, Capitol Environmental 2008 quote, Ferguson Surveying 2008 quote, PEL 2008 quote, and Engineer's Estimates. Costs are based on present worth. Escalation assumptions were not included in costs.

3) Excavation costs were based on RS Means (2005 edition using a 3% annual increase to 2010). Costs are based on present worth. Escalation assumptions were not included in costs.

4) *Mobilization/Demobilization* costs will include site setup, facilities, utility location, signage, security, decon cell, dust suppression, site teardown/restoration, and demobilization.

5) *Construction Oversight/Project Management* costs include daily oversight, health and safety requirements, project management requirements, subcontractor procurements, and any day to day requirements deemed necessary.

6) *Reporting* costs include development of the work plan and other required planning documents including but not limited to quality control, health and safety, environmental protection, and completion reporting (as-built drawings).

Abbreviations and Acronyms:

EA - Each
LS - Lump Sum

QA/QC - Quality Assurance/Quality control

CY - Cubic Yard
TN - Ton
IDW - Investigation Derived Waste
MW - Monitoring Well
PCE - Tetrachloroethene

Alternative 3 - In-Situ Groundwater Treatment and
Soil and Powder Well Sediment Removal and Offsite Disposal
Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Unit Cost	Total	Source	Assumptions
Confirmation Sampling for Soil Removal Activities						
Laboratory Analysis						
Arsenic Analysis	48	EA	$25	$1,200	Vendor Quote	5 soil borings each at 2 removal areas for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Arsenic and Lead Analysis	24	EA	$51	$1,224	Vendor Quote	5 soil borings at 1 removal area for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC
Thallium Analysis	48	EA	$25	$1,200	Vendor Quote	5 soil borings each at 2 removal areas for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Lead Analysis	24	EA	$26	$624	Vendor Quote	5 soil borings at 1 removal area for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Aroclor 1260 Analysis	24	EA	$26	$624	Vendor Quote	5 soil borings at 1 removal area for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Fieldwork Expenses						
Labor	1	LS	$7,200	$7,200	Engineer's Estimate	Fieldwork, office support
Equipment	1	LS	$725	$725	Engineer's Estimate	Sampling and health and safety equipment
Travel	1	LS	$288	$288	Engineer's Estimate	Assumes 3 days to complete surface soil delineation.
Subtotal				**$13,085**		
Excavation/Backfill/Transport and Disposal of Soil and Sediment						
Site Preparation						
Preparation	1	LS	$6,540	$6,540	Engineer's Estimate	Subcontractor labor, backhoe, 10-wheel dump truck, private utility
Laboratory Analysis						
Waste Characterization	7	EA	$900	$6,300	Engineer's Estimate	Characterization of soil at each removal area for offsite disposal, sample technician, equipment, and supplies.
Excavation						
Soil Excavation - Arsenic and Lead	245	CY	$70	$17,150	Engineer's Estimate	Arsenic and lead excavation dimensions:
Soil Excavation - Thallium	155	CY	$70	$10,850	Engineer's Estimate	Thallium excavation dimensions: 915sf x 2' and 1,175sf x 2'
Soil Excavation - Aroclor 1260	65	CY	$70	$4,550	Engineer's Estimate	Aroclor 1,260 excavation dimension: 875sf x 2'
IDW Management						
Transportation & Disposal-Special Waste (conversion factor 1.7)	160	TN	$72	$11,520	Engineer's Estimate	Assumes 20% of soil IDW is special waste.
Transportation & Disposal-Hazardous (conversion factor 1.7)	474	TN	$278	$131,772	Engineer's Estimate	Assumes 60% of soil IDW is hazardous.
Transportation & Disposal-Hazardous Pre-treat (conversion factor 1.7)	160	TN	$422	$67,520	Engineer's Estimate	Assumes 20% of soil IDW is hazardous requiring pre-treatment.
Restoration						
Backfill with Imported Fill (conversion factor of 1.6)	744	TN	$41	$30,504	Engineer's Estimate	Subcontractor labor, compactor, backhoe, 10-wheel dump truck.
Seeding and straw	7,115	SF	$0.15	$1,067	Engineer's Estimate	Standard grass seed.
Watering	1	LS	$22,660	$22,660	Engineer's Estimate	Daily watering for 6 weeks - includes water truck services.

Alternative 3 - In-Situ Groundwater Treatment and
Soil and Powder Well Sediment Removal and Offsite Disposal
Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Unit Cost	Total	Source	Assumptions
Survey Support						
Surveying of Excavation Extents	1	LS	$2,200	$2,200	Vendor Quote	Includes survey of 4 corners at 7 removal areas, data evaluation and report.
Air Monitoring						
Air Monitoring	10	DY	$29	$290	Engineer's Estimate	Breathing zone monitoring during excavation activities.
Fieldwork Expenses						
Labor	1	LS	$10,000	$10,000	Engineer's Estimate	Fieldwork and office support.
Equipment	1	LS	$300	$300	Engineer's Estimate	Sampling and health and safety equipment
Travel	1	LS	$950	$950	Engineer's Estimate	Assumes 2 weeks to complete surface soil removal and backfill.
Subtotal				**$324,173**		
Powder Well Sediment Removal						
Sediment Removal						
Sediment Removal Services	28	CY	$174	$4,872	Vendor Quote	Removal of 28 yd^3 of sediment from 22 powder wells via vacuum truck.
IDW Management						
Transportation and Disposal - Special Waste (conversion factor of 1.29 for sediment)	18	TN	$70	$1,260	Engineer's Estimate	Disposal of 36 tons of sediment as 50% as special waste.
Transportation and Disposal - Hazardous (conversion factor of 1.29 for sediment)	18	TN	$270	$4,860	Engineer's Estimate	Disposal of 36 tons of sediment as 50% hazardous.
Laboratory Analysis						
Waste Characterization	1	LS	$2,283	$2,283	Vendor Quote	
Fieldwork Expenses						
Labor	1	LS	$6,000	$6,000	Engineer's Estimate	Fieldwork, office support.
Travel Expenses	1	LS	$318	$318	Engineer's Estimate	
Equipment	1	LS	$725	$725	Engineer's Estimate	
Air Monitoring						
Air Monitoring	3	DY	$29	$87	Engineer's Estimate	Breathing zone monitoring during sediment removal activities.
Subtotal				**$19,145**		
Pre-Remedial Design Sampling						
Installation of Groundwater Sampling Points						
Drilling Services	1	LS	$9,500	$9,500	Vendor Quote	Installation of 7 temporary wells, abandonment, drums, mobilization.
Laboratory Analysis						
Analysis of COCs	11	EA	$60	$660	Vendor Quote	Analysis of PCE; includes QA/QC.
Waste Characterization	2	EA	$289	$578	Vendor Quote	
IDW Management						
Transportation and Offsite Disposal	1	LS	$1,700	$1,700	Vendor Quote	Offsite disposal of 4 soil drums. Liquid IDW discharged via sanitary sewer system.
Fieldwork Expenses						
Labor	1	LS	$7,600	$7,600	Engineer's Estimate	Fieldwork, office support, and data validation.
Equipment	1	LS	$1,375	$1,375	Engineer's Estimate	Sampling and health and safety equipment
Travel Expenses	1	LS	$318	$318	Engineer's Estimate	Assumes 3 days to complete groundwater delineation.

Alternative 3 - In-Situ Groundwater Treatment and
Soil and Powder Well Sediment Removal and Offsite Disposal
Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Unit Cost	Total	Source	Assumptions
Survey Support						
Survey of Sample Locations	1	LS	$1,630	$1,630	Vendor Quote	Includes survey of 7 groundwater sample points, data evaluation and report.
Subtotal				**$23,361**		
Well Abandonment / Installation						
Well Abandonment and Installation at Plumes A and C						
Abandonment and Installation Services	1	LS	$9,370	$9,370	Vendor Quote	Abandonment of 4 shallow 2" well (MW-105, MW-106, MW-114, MW-111) and 1 deep well (MW-117), and installation of 3 shallow 2" wells (2 at Plume A and 1 at Plume C); includes well development, drums, and mobilization.
IDW Management						
Transportation and Offsite Disposal	1	LS	$4,400	$4,400	Vendor Quote	Offsite disposal of 12 soil drums and discharge of liquid IDW via sanitary sewer system.
Fieldwork Expenses						
Labor	1	LS	$9,200	$9,200	Engineer's Estimate	Fieldwork and office support.
Equipment and Supplies	1	LS	$725	$725	Engineer's Estimate	
Travel Expenses	1	LS	$404	$404	Engineer's Estimate	Assumes 4 days to complete abandonment/installation activities.
Survey Support						
Survey of New Wells	1	LS	$1,470	$1,470	Vendor Quote	Includes survey of 3 wells, data evaluation and report.
Subtotal				**$25,569**		
Soil Mixing at Plume A						
Implementation						
Subcontractor Mobilization and Demobilization	1	LS	$130,000	$130,000	Vendor Quote	Treatment Area: 2,100 ft^2 Target Treatment Zone: 1-29 feet bgs Treatment Zone Volume: 59,000 ft^3 Mass of Product required: 36,450 lbs Includes the following: 40' x 40' concrete pad removal, 1-pass trenching machine, Decontamination pad, IDW disposal, Mobilization/Demobilization, Installation of sediment and erosion control, Placement of topsoil over disturbed areas, Seeding, fertilizer, and straw, Daily watering for 6 weeks, and Site clean-up
Chemical Reduction Product	1	LS	$57,750	$57,750	Vendor Quote	
Enhanced Reductive Dechlorination Product Preparation	1	LS	$24,750	$24,750	Vendor Quote	
Soil Mixing	1	LS	$300,000	$300,000	Vendor Quote	
Chemical Application	1	LS	$32,850	$32,850	Vendor Quote	
Decontamination of Equipment	1	LS	$12,500	$12,500	Vendor Quote	
IDW Management of Excess Soil	1	LS	$10,425	$10,425	Vendor Quote	
Sewer Line Removal	1	LS	$2,000	$2,000	Engineer's Estimate	
Site Restoration	1	LS	$20,960	$20,960	Vendor Quote	
Project Management	1	LS	$4,600	$4,600	Vendor Quote	
Fieldwork Expenses						
Labor	1	LS	$20,480	$20,480	Engineer's Estimate	Fieldwork, office support.
Equipment	1	LS	$1,500	$1,500	Engineer's Estimate	Sampling and health and safety equipment.
Travel	1	LS	$1,390	$1,390	Engineer's Estimate	Assumes 4 weeks to complete soil mixing.
Subtotal				**$619,205**		

Alternative 3 - In-Situ Groundwater Treatment and
Soil and Powder Well Sediment Removal and Offsite Disposal
Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Unit Cost	Total	Source	Assumptions
Groundwater Monitoring at Plume A - 2 Events						
Groundwater Monitoring at Plume A						
Laboratory Analysis						
Analysis of COCs	2	EA	$60	$120	Vendor Quote	2 monitoring wells within Plume A to be sampled approximately one month following soil mixing activities (will coincide with the first annual groundwater monitoring event). The second event will occur 12 weeks later.
Soil and Liquid IDW Characterization	1	EA	$289	$289	Vendor Quote	1 Liquid IDW sample/event.
IDW Management						
Transportation and Disposal	1	LS	$2,210	$2,210	Vendor Quote	Disposal of 1 liquid IDW drum via sanitary sewer system/event.
Fieldwork Expenses						
Labor	1	LS	$5,000	$5,000	Engineer's Estimate	Fieldwork, office support, project management.
Equipment	1	LS	$808	$808	Engineer's Estimate	Sampling and health and safety equipment.
Travel	1	LS	$318	$318	Engineer's Estimate	Assumes 4-day rentals to complete soil sampling/event.
Subtotal				**$8,745**		
Groundwater Monitoring at Plume A - Year 1 through 5						
Laboratory Analysis						
Analysis of COCs	80	EA	$60	$4,800	Vendor Quote	10 monitoring wells sampled per event. Annual sampling for Years 1 through 5; includes QA/QC. Includes gauging of wells.
Waste Characterization	5	EA	$289	$1,445	Vendor Quote	
IDW Management						
Transportation and Disposal	5	EA	$1,516	$7,580	Vendor Quote	Disposal of liquid IDW via sanitary sewer system.
Fieldwork Expenses						
Labor	5	EA	$8,400	$42,000	Engineer's Estimate	Fieldwork, office support, data validation for 5 events.
Equipment and Supplies	5	EA	$808	$4,040	Engineer's Estimate	Sampling and health and safety equipment
Travel Expenses	5	EA	$318	$1,590	Engineer's Estimate	Assumes 2 days to complete groundwater sampling activities.
Subtotal				**$61,455**		
Remedial Design			6%	**$65,684**		
Work Planning			6%	**$65,684**		
Contingency			25%	**$273,685**		
Subtotal				**$405,053**		
Total Cost of Alternative 3 with Remedial Design and Contingency				**$1,499,791**		
Construction Oversight/Project Management			10%	**$149,979**		
Reporting (Includes RACR and Annual LTM Report)			15%	**$224,969**		
Subtotal				**$374,948**		
Total Cost				**$1,874,739**		
Operation and Maintenance Costs - Year 6 through 50						
Laboratory Analysis						
Analysis of COCs	16	EA	$60	$960	Vendor Quote	10 monitoring wells sampled every 5 years; includes QA/QC.
Waste Characterization	1	EA	$289	$289	Vendor Quote	

Alternative 3 - In-Situ Groundwater Treatment and
Soil and Powder Well Sediment Removal and Offsite Disposal
Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Unit Cost	Total	Source	Assumptions
IDW Management						
Transportation and Disposal	1	LS	$1,516	$1,516	Vendor Quote	Disposal of liquid IDW via sanitary sewer system.
Fieldwork Expenses						
Labor	1	LS	$8,400	$8,400	Engineer's Estimate	Fieldwork, office support, data validation per event.
Equipment	1	LS	$808	$808	Engineer's Estimate	Sampling and health and safety equipment
Travel Expenses	1	LS	$232	$232	Engineer's Estimate	Assumes 2 days to complete groundwater sampling activities.
Reporting						
Groundwater Monitoring and Inspection Report	1	LS	$12,000	$12,000	Engineer's Estimate	
Data Management	1	LS	$2,400	$2,400	Engineer's Estimate	
Subtotal				**$26,605**		
Contingency			30%	**$7,982**		
Subtotal				**$34,587**		
Project Management			10%	**$3,459**		
Technical Support			20%	**$6,917**		
Subtotal				**$10,376**		
Total Operation and Maintenance Costs Per Event				**$44,962**		
Periodic Costs - Year 6 through 50						
5-year Review	LS	1	$15,000	$15,000	Engineer's	
Periodic Costs Per 5-year Review				**$15,000**		
Total O&M and 5-year Review				**$59,962**		
			2.7%	Discount Rate		
			0.0%	Inflation Rate		
Present Value Analysis						
Present Worth Cost of Five-Year Review O&M Cost			27.2621	$1,675,392		
Present Worth of Periodic Costs in Year 5			0.8753	$52,484		
Present Worth of Periodic Costs in Year 10			0.7661	$45,938		
Present Worth of Periodic Costs in Year 15			0.6706	$40,209		
Present Worth of Periodic Costs in Year 20			0.5869	$35,194		
Present Worth of Periodic Costs in Year 25			0.5137	$30,805		
Present Worth of Periodic Costs in Year 30			0.4497	$26,963		
Present Worth of Periodic Costs in Year 35			0.3936	$23,600		
Present Worth of Periodic Costs in Year 40			0.3445	$20,657		
Present Worth of Periodic Costs in Year 45			0.3015	$18,080		
Present Worth of Periodic Costs in Year 50			0.2639	$15,825		
Total Present Worth Costs				**$1,985,148**		
TOTAL CAPITAL AND PRESENT WORTH COSTS				**$3,859,887**		

Note:

1) The estimate above is considered budgetary-level cost estimating, suitable for use in project evaluation and planning. Actual construction costs are expected to vary from these estimates due to market conditions, actual costs of purchased materials, quantity variations, regulatory requirements, and other factors existing at the time of construction.

2) Costs were based on RS Means (2005 edition using a 4% annual increase to 2010). MRK Exploration quote, Environmental Works quote, Summit quote, Capitol Environmental 2008 quote, Ferguson Surveying 2008 quote, PEL 2008 quote, and Engineer's Estimates. Costs are based on present worth. Escalation assumptions were not included in costs.

3) Excavation costs were based on RS Means (2005 edition using a 3% annual increase to 2010). Costs are based on present worth. Escalation assumptions were not included in costs.

4) *Mobilization/Demobilization* costs will include site setup, facilities, utility location, signage, security, decon cell, dust suppression, site teardown/restoration, and demobilization.

5) *Construction Oversight/Project Management* costs include daily oversight, health and safety requirements, project management requirements, subcontractor procurements, and any day to day requirements deemed necessary.

6) *Reporting* costs include development of the work plan and other required planning documents including but not limited to quality control, health and safety, environmental protection, and completion reporting (as-built drawings).

Description	Qty	Unit	Unit Cost	Total	Source	Assumptions
Abbreviations and Acronyms:						
EA - Each						
LS - Lump Sum						
QA/QC - Quality Assurance/Quality control						
CY - Cubic Yard						
TN - Ton						
IDW - Investigation Derived Waste						
MW - Monitoring Well						
PCE - *Tetrachloroethene*						
TCE - Trichloroethene						
1,1,1,2-TeCA - 1,1,1,2-tetrachloroethane						
1,1,2,2-TeCA - 1,1,2,2-tetrachloroethane						

Alternative 4 - Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal, and Offsite Disposal

Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Cost	Total	Source	Assumptions
Confirmation Sampling for Soil Removal Activities						
Laboratory Analysis						
Arsenic Analysis	48	EA	$25	$1,200	Vendor Quote	5 soil borings each at 2 removal areas for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Arsenic and Lead Analysis	24	EA	$51	$1,224	Vendor Quote	5 soil borings at 1 removal area for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Thallium Analysis	48	EA	$25	$1,200	Vendor Quote	5 soil borings each at 2 removal areas for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples
Lead Analysis	24	EA	$26	$624	Vendor Quote	5 soil borings at 1 removal area for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Aroclor 1260 Analysis	24	EA	$26	$624	Vendor Quote	5 soil borings at 1 removal area for collection of 0-6", 6-12", 12-18", and 18-24" intervals; includes QA/QC samples.
Fieldwork Expenses						
Labor	1	LS	$7,200	$7,200	Engineer's Estimate	Fieldwork, office suppor.
Equipment	1	LS	$725	$725	Engineer's Estimate	Sampling and health and safety equipment
Travel	1	LS	$288	$288	Engineer's Estimate	Assumes 3 days to complete surface soil delineation.
Subtotal				**$13,085**		
Excavation/Backfill/Transport and Disposal of Soil and Sediment						
Site Preparation						
Preparation	1	LS	$6,540	$6,540	Engineer's Estimate	Subcontractor labor, backhoe, 10-wheel dump truck, private utility locate.
Laboratory Analysis						
Waste Characterization	7	EA	$900	$6,300	Engineer's Estimate	Characterization of soil at each removal area for offsite disposal, sample technician, equipment, and supplies.
Excavation						
Soil Excavation - Arsenic and Lead	245	CY	$70	$17,150	Engineer's Estimate	Arsenic and lead excavation dimensions: 475sf x 1', 1125sf x 2', 1210sf x 2', and 1340sf x 1'
Soil Excavation - Thallium	155	CY	$70	$10,850	Engineer's Estimate	Thallium excavation dimensions: 915sf x 2' and 1,175sf x 2'
Soil Excavation - Aroclor 1260	65	CY	$70	$4,550	Engineer's Estimate	Aroclor 1,260 excavation dimension: 875sf x 2'
IDW Management						
Transportation & Disposal-Special Waste (conversion factor 1 7)	160	TN	$72	$11,520	Engineer's Estimate	Assumes 20% of soil IDW is special waste.
Transportation & Disposal-Hazardous (conversion factor 1.7)	474	TN	$278	$131,772	Engineer's Estimate	Assumes 60% of soil IDW is hazardous.
Transportation & Disposal-Hazardous Pre-treat (conversion factor 1.7)	160	TN	$422	$67,520	Engineer's Estimate	Assumes 20% of soil IDW is hazardous requiring pre-treatment.
Restoration						
Backfill with Imported Fill (conversion factor of 1.6)	744	TN	$41	$30,504	Engineer's Estimate	Subcontractor labor, compactor, backhoe, 10-wheel dump truck.
Seeding and straw	7,115	SF	$0.15	$1,067	Engineer's Estimate	Standard grass seed.
Watering	1	LS	$22,660	$22,660	Engineer's Estimate	Daily watering for 6 weeks - includes water truck services.

Alternative 4 - Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal, and Offsite Disposal

Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Cost	Total	Source	Assumptions
Survey Support						
Surveying of Excavation Extents	1	LS	$2,200	$2,200	Vendor Quote	Includes survey of 4 corners at 7 removal areas, data evaluation and report.
Air Monitoring						
Air Monitoring	10	DY	$29	$290	Engineer's Estimate	Breathing zone monitoring during excavation activities.
Fieldwork Expenses						
Labor	1	LS	$10,000	$10,000	Engineer's Estimate	Fieldwork and office support.
Equipment	1	LS	$300	$300	Engineer's Estimate	Sampling and health and safety equipment
Travel	1	LS	$950	$950	Engineer's Estimate	Assumes 2 weeks to complete surface soil removal and backfill.
Subtotal				**$324,173**		
Powder Well Sediment Removal						
Sediment Removal						
Sediment Removal Services	28	CY	$174	$4,872	Vendor Quote	Removal of 28 yd^3 of sediment from 22 powder wells via vacuum truck.
IDW Management						
Transportation and Disposal - Special Waste (conversion factor of 1.29 for sediment)	18	TN	$70	$1,260	Engineer's Estimate	Disposal of 36 tons of sediment as 50% as special waste.
Transportation and Disposal - Hazardous (conversion factor of 1.29 for sediment)	18	TN	$270	$4,860	Engineer's Estimate	Disposal of 36 tons of sediment as 50% hazardous.
Laboratory Analysis						
Waste Characterization	1	LS	$2,283	$2,283	Vendor Quote	
Fieldwork Expenses						
Labor	1	LS	$6,000	$6,000	Engineer's Estimate	Fieldwork, office support.
Travel Expenses	1	LS	$318	$318	Engineer's Estimate	
Equipment	1	LS	$725	$725	Engineer's Estimate	
Air Monitoring						
Air Monitoring	3	DY	$29	$87	Engineer's Estimate	Breathing zone monitoring during sediment removal activities.
Subtotal				**$19,145**		
Pre-Remedial Design Sampling						
Installation of Groundwater Sampling Points						
Drilling Services	1	LS	$9,500	$9,500	Vendor Quote	Installation of 7 temporary wells, abandonment, drums, mobilization.
Laboratory Analysis						
Analysis of COCs	11	EA	$60	$660	Vendor Quote	Analysis of PCE; includes QA/QC.
Waste Characterization	2	EA	$289	$578	Vendor Quote	
IDW Management						
Transportation and Offsite Disposal	1	LS	$1,700	$1,700	Vendor Quote	Offsite disposal of 4 soil drums Liquid IDW discharged via sanitary sewer system.
Fieldwork Expenses						
Labor	1	LS	$7,600	$7,600	Engineer's Estimate	Fieldwork, office support, and data validation.
Equipment	1	LS	$1,375	$1,375	Engineer's Estimate	Sampling and health and safety equipment
Travel Expenses	1	LS	$318	$318	Engineer's Estimate	Assumes 3 days to complete groundwater delineation.

Alternative 4 - Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal, and Offsite Disposal
Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Cost	Total	Source	Assumptions
Survey Support						
Survey of Sample Locations	1	LS	$1,630	$1,630	Vendor Quote	Includes survey of 7 groundwater sample points, data evaluation and report.
Subtotal				**$23,361**		
Well Abandonment / Installation						
Well Abandonment and Installation at Plumes A and C						
Abandonment and Installation Services	1	LS	$9,370	$9,370	Vendor Quote	Abandonment of 4 shallow 2" well (MW-105, MW-106, MW-114, MW-111) and 1 deep well (MW-117), and installation of 3 shallow 2" wells (2 at Plume A and 1 at Plume C); includes well development, drums, and mobilization.
IDW Management						
Transportation and Offsite Disposal	1	LS	$4,400	$4,400	Vendor Quote	Offsite disposal of 12 soil drums and discharge of liquid IDW via sanitary sewer system.
Fieldwork Expenses						
Labor	1	LS	$9,200	$9,200	Engineer's Estimate	Fieldwork and office support.
Equipment and Supplies	1	LS	$725	$725	Engineer's Estimate	
Travel Expenses	1	LS	$404	$404	Engineer's Estimate	Assumes 4 days to complete abandonment/installation activities.
Survey Support						
Survey of New Wells	1	LS	$1,470	$1,470	Vendor Quote	Includes survey of 3 wells, data evaluation and report.
Subtotal				**$25,569**		
Excavation/Backfill/Transport and Disposal at Plume A						
Plans/Site Preparation/Mob/Demob						
Plans/Site Preparation/Mob	1	LS	$57,680	$57,680	Engineer's Estimate	Planning, Subcontractor labor, cranes, sheetpile driver, backhoe, and 10-wheel dump truck.
Install/Remove Shoring						
Sheetpile (north side)	2,500	SF	$15	$37,500	Engineer's Estimate	Perimeter length of approximately 83 feet to be sheetpiled.
Struts/Wales	7,000	LB	$0.50	$3,500	Engineer's Estimate	
Misc Shoring	1	LS	$2,410	$2,410	Engineer's Estimate	
Ironworker/Welder/Labor/Oil/Hydr Driver/Crane	1	LS	$33,720	$33,720	Engineer's Estimate	
Removal of Sheets	1	LS	$8,858	$8,858	Engineer's Estimate	Subcontractor labor, ironworkers, welders, operators, crane
Laboratory Analysis						
Waste Characterization	5	EA	$1,070	$5,350	Engineer's Estimate	Characterization of soil at Plume A for offsite disposal (every 500 yd3), sample technician, data validation, equipment, and supplies.
Excavate Exploratory Trench						
Exploratory Trench	60	CY	$52	$3,120	Engineer's Estimate	Subcontractor labor, backhoe, 10-wheel dump truck. Trench to verify presence/absence of utilities before sheet piling.

Alternative 4 - Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal, and Offsite Disposal
Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Cost	Total	Source	Assumptions
Excavation and Removal of Concrete Pad and Sewer Line						
Soil Excavation - Plume A Source Area	2,280	CY	$11	$25,080	Engineer's Estimate	Plume A source area conservatively estimated at 45' x 45' x 30' for costing purposes. Includes removal of 40' x 40' concrete pad.
Sewer Line Removal	1	LS	$2,000	$2,000	Engineer's Estimate	
Excavation Water Management						
Water Truck and Labor	1	LS	$14,460	$14,460	Engineer's	Calculated inflow of groundwater at 660 gallons/day for 20 days and disposal of recovered groundwater via an onsite sanitary sewer inlet.
Waste Characterization	1	LS	$15,180	$15,180	Engineer's	
Transportation and Disposal via Sanitary Sewer	1	LS	$6,510	$6,510	Engineer's Estimate	
IDW Management						
Transportation & Disposal-Contaminated (conversion factor 1.7)	2,907	TN	$62	$180,234	Engineer's Estimate	Assumes 75% of soil IDW is contaminated.
Transportation & Disposal-Hazardous (conversion factor 1.7)	775	TN	$227	$175,925	Engineer's Estimate	Assumes 20% of soil IDW is hazardous.
Transportation & Disposal-Hazardous_Pre-treat (conversion factor 1.7)	194	TN	$263	$51,022	Engineer's Estimate	Assumes 5% of soil IDW is hazardous requiring pre-treatment.
Restoration						
Backfill with Imported Fill	3,648	TN	$15	$54,720	Engineer's Estimate	Subcontractor labor, compactor, backhoe, 10-wheel dump truck.
Topsoil, seeding, straw, erosion and sediment	1	LS	$37,330	$37,330	Engineer's	Daily watering for 6 weeks
Survey Support						
Surveying of Excavation	1	LS	$2,200	$2,200	Vendor Quote	Includes survey of excavation at Plume A, data evaluation and report.
Air Monitoring						
Air Monitoring	2	EA	$145	$290	Engineer's Estimate	Breathing zone monitoring during excavation activities.
Fieldwork Expenses						
Labor	1	LS	$24,800	$24,800	Engineer's Estimate	Fieldwork and office support.
Equipment	1	LS	$500	$500	Engineer's Estimate	Sampling and health and safety equipment
Travel	1	LS	$1,840	$1,840	Engineer's Estimate	Assumes 20 days to complete excavation.
Subtotal				**$744,229**		
Groundwater Monitoring at Plume A - Year 1 through 5						
Laboratory Analysis						
Analysis of COCs	80	EA	$60	$4,800	Vendor Quote	10 monitoring wells sampled per event. Annual sampling for Years 1 through 5; includes QA/QC. Includes gauging of all wells.
Waste Characterization	5	EA	$289	$1,445	Vendor Quote	
IDW Management						
Transportation and Disposal	5	LS	$1,516	$7,580	Vendor Quote	Disposal of liquid IDW via sanitary sewer system.
Fieldwork Expenses						
Labor	5	LS	$8,400	$42,000	Engineer's Estimate	Fieldwork, office support, data validation for 5 events.
Equipment and Supplies	5	LS	$808	$4,040	Engineer's Estimate	Sampling and health and safety equipment
Travel Expenses	5	LS	$318	$1,590	Engineer's Estimate	Sampling and health and safety equipment
Subtotal				**$61,455**		

Alternative 4 - Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal, and Offsite Disposal
Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Cost	Total	Source	Assumptions
Survey Support						
Survey of Sample Locations	1	LS	$1,630	$1,630	Vendor Quote	Includes survey of 7 groundwater sample points, data evaluation and report.
Subtotal				**$23,361**		
Well Abandonment / Installation						
Well Abandonment and Installation at Plumes A and C						
Abandonment and Installation Services	1	LS	$9,370	$9,370	Vendor Quote	Abandonment of 4 shallow 2" well (MW-105, MW-106, MW-114, MW-111) and 1 deep well (MW-117), and installation of 3 shallow 2" wells (2 at Plume A and 1 at Plume C); includes well development, drums, and mobilization.
IDW Management						
Transportation and Offsite Disposal	1	LS	$4,400	$4,400	Vendor Quote	Offsite disposal of 12 soil drums and discharge of liquid IDW via sanitary sewer system.
Fieldwork Expenses						
Labor	1	LS	$9,200	$9,200	Engineer's Estimate	Fieldwork and office support.
Equipment and Supplies	1	LS	$725	$725	Engineer's Estimate	
Travel Expenses	1	LS	$404	$404	Engineer's Estimate	Assumes 4 days to complete abandonment/installation activities.
Survey Support						
Survey of New Wells	1	LS	$1,470	$1,470	Vendor Quote	Includes survey of 3 wells, data evaluation and report.
Subtotal				**$25,569**		
Excavation/Backfill/Transport and Disposal at Plume A						
Plans/Site Preparation/Mob/Demob						
Plans/Site Preparation/Mob	1	LS	$57,680	$57,680	Engineer's Estimate	Planning, Subcontractor labor, cranes, sheetpile driver, backhoe, and 10-wheel dump truck.
Install/Remove Shoring						
Sheetpile (north side)	2,500	SF	$15	$37,500	Engineer's Estimate	Perimeter length of approximately 83 feet to be sheetpiled.
Struts/Wales	7,000	LB	$0.50	$3,500	Engineer's Estimate	
Misc Shoring	1	LS	$2,410	$2,410	Engineer's Estimate	
Ironworker/Welder/Labor/Oil/Hydr Driver/Crane	1	LS	$33,720	$33,720	Engineer's Estimate	
Removal of Sheets	1	LS	$8,858	$8,858	Engineer's Estimate	Subcontractor labor, ironworkers, welders, operators, crane
Laboratory Analysis						
Waste Characterization	5	EA	$1,070	$5,350	Engineer's Estimate	Characterization of soil at Plume A for offsite disposal (every 500 yd3), sample technician, data validation, equipment, and supplies.
Excavate Exploratory Trench						
Exploratory Trench	60	CY	$52	$3,120	Engineer's Estimate	Subcontractor labor, backhoe, 10-wheel dump truck. Trench to verify presence/absence of utilities before sheet piling.

Alternative 4 - Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal, and Offsite Disposal
Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Cost	Total	Source	Assumptions
Excavation and Removal of Concrete Pad and Sewer Line						
Soil Excavation - Plume A Source Area	2,280	CY	$11	$25,080	Engineer's Estimate	Plume A source area conservatively estimated at 45' x 45' x 30' for costing purposes. Includes removal of 40' x 40' concrete pad.
Sewer Line Removal	1	LS	$2,000	$2,000	Engineer's Estimate	
Excavation Water Management						
Water Truck and Labor	1	LS	$14,460	$14,460	Engineer's	Calculated inflow of groundwater at 660 gallons/day for 20 days and disposal of recovered groundwater via an onsite sanitary sewer inlet.
Waste Characterization	1	LS	$15,180	$15,180	Engineer's	
Transportation and Disposal via Sanitary Sewer	1	LS	$6,510	$6,510	Engineer's Estimate	
IDW Management						
Transportation & Disposal-Contaminated (conversion factor 1.7)	2,907	TN	$62	$180,234	Engineer's Estimate	Assumes 75% of soil IDW is contaminated.
Transportation & Disposal-Hazardous (conversion factor 1.7)	775	TN	$227	$175,925	Engineer's Estimate	Assumes 20% of soil IDW is hazardous.
Transportation & Disposal-Hazardous_Pre-treat (conversion factor 1.7)	194	TN	$263	$51,022	Engineer's Estimate	Assumes 5% of soil IDW is hazardous requiring pre-treatment.
Restoration						
Backfill with Imported Fill	3,648	TN	$15	$54,720	Engineer's Estimate	Subcontractor labor, compactor, backhoe, 10-wheel dump truck.
Topsoil, seeding, straw, erosion and sediment	1	LS	$37,330	$37,330	Engineer's	Daily watering for 6 weeks
Survey Support						
Surveying of Excavation	1	LS	$2,200	$2,200	Vendor Quote	Includes survey of excavation at Plume A, data evaluation and report.
Air Monitoring						
Air Monitoring	2	EA	$145	$290	Engineer's Estimate	Breathing zone monitoring during excavation activities.
Fieldwork Expenses						
Labor	1	LS	$24,800	$24,800	Engineer's Estimate	Fieldwork and office support.
Equipment	1	LS	$500	$500	Engineer's Estimate	Sampling and health and safety equipment
Travel	1	LS	$1,840	$1,840	Engineer's Estimate	Assumes 20 days to complete excavation.
Subtotal				**$744,229**		
Groundwater Monitoring at Plume A - Year 1 through 5						
Laboratory Analysis						
Analysis of COCs	80	EA	$60	$4,800	Vendor Quote	10 monitoring wells sampled per event. Annual sampling for Years 1 through 5; includes QA/QC. Includes gauging of all wells.
Waste Characterization	5	EA	$289	$1,445	Vendor Quote	
IDW Management						
Transportation and Disposal	5	LS	$1,516	$7,580	Vendor Quote	Disposal of liquid IDW via sanitary sewer system.
Fieldwork Expenses						
Labor	5	LS	$8,400	$42,000	Engineer's Estimate	Fieldwork, office support, data validation for 5 events.
Equipment and Supplies	5	LS	$808	$4,040	Engineer's Estimate	Sampling and health and safety equipment
Travel Expenses	5	LS	$318	$1,590	Engineer's Estimate	Sampling and health and safety equipment
Subtotal				**$61,455**		

Alternative 4 - Groundwater Source Removal by Excavation, Soil and Powder Well Sediment Removal, and Offsite Disposal

Feasibility Study Report - St. Louis Ordnance Plant, Former Hanley Area

Description	Qty	Unit	Cost	Total	Source	Assumptions
Remedial Design			6%	$72,661		
Work Planning			6%	$72,661		
Contingency			25%	$302,754		
Subtotal				$448,076		
Total Cost of Alternative 2 with Remedial Design and Contingency				$1,659,094		
Construction Oversight/Project Management			10%	$165,909		
Reporting (Includes RACR and Annual LTM			15%	$248,864		
Subtotal				$414,773		
Total Cost				$2,073,867		
Operation and Maintenance Costs - Year 6 through 50						
Laboratory Analysis						
Analysis of COCs	16	EA	$60	$960	Vendor Quote	10 monitoring wells sampled every 5 years; includes QA/QC.
Waste Characterization	1	EA	$289	$289	Vendor Quote	
IDW Management						
Transportation and Disposal	1	LS	$1,516	$1,516	Vendor Quote	Disposal of liquid IDW via sanitary sewer system.
Fieldwork Expenses						
Labor	1	LS	$8,400	$8,400	Engineer's Estimate	Fieldwork, office support, data validation per event.
Equipment	1	LS	$808	$808	Engineer's Estimate	Sampling and health and safety equipment
Travel Expenses	1	LS	$232	$232	Engineer's Estimate	Assumes 2 days to complete groundwater sampling activities.
Reporting						
Groundwater Monitoring and Inspection Report	1	LS	$12,000	$12,000	Engineer's Estimate	
Data Management	1	LS	$2,400	$2,400	Engineer's Estimate	
Subtotal				$26,605		
Contingency			30%	$7,982		
Subtotal				$34,587		
Project Management			10%	$3,459		
Technical Support			20%	$6,917		
Subtotal				$10,376		
Total Operation and Maintenance Costs Per				$44,962		
Periodic Costs - Year 7 through 50						
5-year Review	LS	1	$15,000	$15,000	Engineer's	
Periodic Costs Per 5-year Review				$15,000		
Total O&M and 5-year Review				$59,962		
			2.7%	Discount Rate		
			0.0%	Inflation Rate		
Present Value Analysis						
Present Worth Cost of Five-Year Review O&M Cost			27.2621	$1,675,392		
Present Worth of Periodic Costs in Year 6			0.8753	$52,484		
Present Worth of Periodic Costs in Year 11			0.7661	$45,938		
Present Worth of Periodic Costs in Year 16			0.6706	$40,209		
Present Worth of Periodic Costs in Year 21			0.5869	$35,194		
Present Worth of Periodic Costs in Year 26			0.5137	$30,805		
Present Worth of Periodic Costs in Year 31			0.4497	$26,963		
Present Worth of Periodic Costs in Year 36			0.3936	$23,600		
Present Worth of Periodic Costs in Year 41			0.3445	$20,657		
Present Worth of Periodic Costs in Year 46			0.3015	$18,080		
Present Worth of Periodic Costs in Year 50			0.2639	$15,825		
Total Present Worth Costs				$1,985,148		
TOTAL CAPITAL AND PRESENT WORTH COSTS				$4,059,015		

Description	Qty	Unit	Cost	Total	Source	Assumptions

Note:

1) The estimate above is considered budgetary-level cost estimating, suitable for use in project evaluation and planning. Actual construction costs are expected to vary from these estimates due to market conditions, actual costs of purchased materials, quantity variations, regulatory requirements, and other factors existing at the time of construction.

2) Costs were based on RS Means (2005 edition using a 4% annual increase to 2010), MRK Exploration quote, Environmental Works quote, Terra Therm quote, Capitol Environmental 2008 quote, Ferguson Surveying 2008 quote, PEL 2008 quote, and Engineer's Estimates. Costs are based on present worth. Escalation assumptions were not included in costs.

3) Excavation costs were based on RS Means (2005 edition using a 3% annual increase to 2010). Costs are based on present worth. Escalation assumptions were not included in costs.

4) *Mobilization/Demobilization* costs will include site setup, facilities, utility location, signage, security, decon cell, dust suppression, site teardown/restoration, and demobilization.

5) *Construction Oversight/Project Management* costs include daily oversight, health and safety requirements, project management requirements, subcontractor procurements, and any day to day requirements deemed necessary.

6) *Reporting* costs include development of the work plan and other required planning documents including but not limited to quality control, health and safety, environmental protection, and completion reporting (as-built drawings).

TABLE 1

Arsenic Concentrations in Soil Samples

Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Sample Name	Arsenic Concentration (mg/kg)	Qualifier
HA-05-S-00_5/13/2008_0_2	36.3	
SS-219E_2001_0_1	23.5	
SS-228A-1_2001_0_1	18.9	
HA-06-S-00_5/13/2008_0_2	18.2	
NS08B_1998_1_2	16.7	
SS-227O-1_2001_0_1	16.5	
SS-228B-1_2001_0_1	16.5	
NS03B_1998_1_2	15.9	
NS02A_1998_0_1	14.5	
SS-236-1_2001_0_1	14.2	
SS-228E-1_2001_0_1	13.7	J
NS07A_1998_0_1	13.6	
SS-228C-1_2001_0_1	13.6	
SB-006_2005_0_1	13.27	
CSS-015_2005_0_1	13	
SS-227A-1_2001_0_1	11.7	J
NS07B_1998_1_2	11.5	
NS05A_1998_0_1	11.4	
NS13A_1998_0_1	11.4	
SS-DPILE-1_2001_NA_NA	11	J
CSS-014_2005_0_1	10.3	
NS11A_1998_0_1	10.1	
HA-03-S-00_5/13/2008_0_2	10	
SS52B_1991_1_2	10	
NS12A_1998_0_1	9.9	
HA-11-S-00_5/13/2008_0_2	9.42	
HA-02-S-00_5/13/2008_0_2	9.41	
SS45A_1991_0_1	9.31	
HA-15-S-00_5/13/2008_0_2	9.14	
HA-13-S-00_5/13/2008_0_2	9.05	
SB-013_2005_NA_NA	8.95	
SS41A_1991_0_1	8.92	
HA-01-S-00_5/13/2008_0_2	8.82	
PW12_2001_7_8	8.59	J
SS46B_1991_1_2	8.44	
HA-12-S-00_5/13/2008_0_2	8.41	
CSS-013_2005_0_1	8.3	
SS-218A-1_2001_0_1	8.25	
HA-14-S-00_5/13/2008_0_2	8.19	
HA-07-S-00_5/13/2008_0_2	8.11	
SS-220-3_2001_0_1	8.08	J
HA-10-S-00_5/13/2008_0_0.25	8.06	
SB-009_2005_NA_NA	7.85	
NS11B_1998_1_2	7.8	
NS14A_1998_6_8	7.8	
SB-008_2005_NA_NA	7.56	
CSS-012_2005_0_1	7.5	

TABLE 1
Arsenic Concentrations in Soil Samples
Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

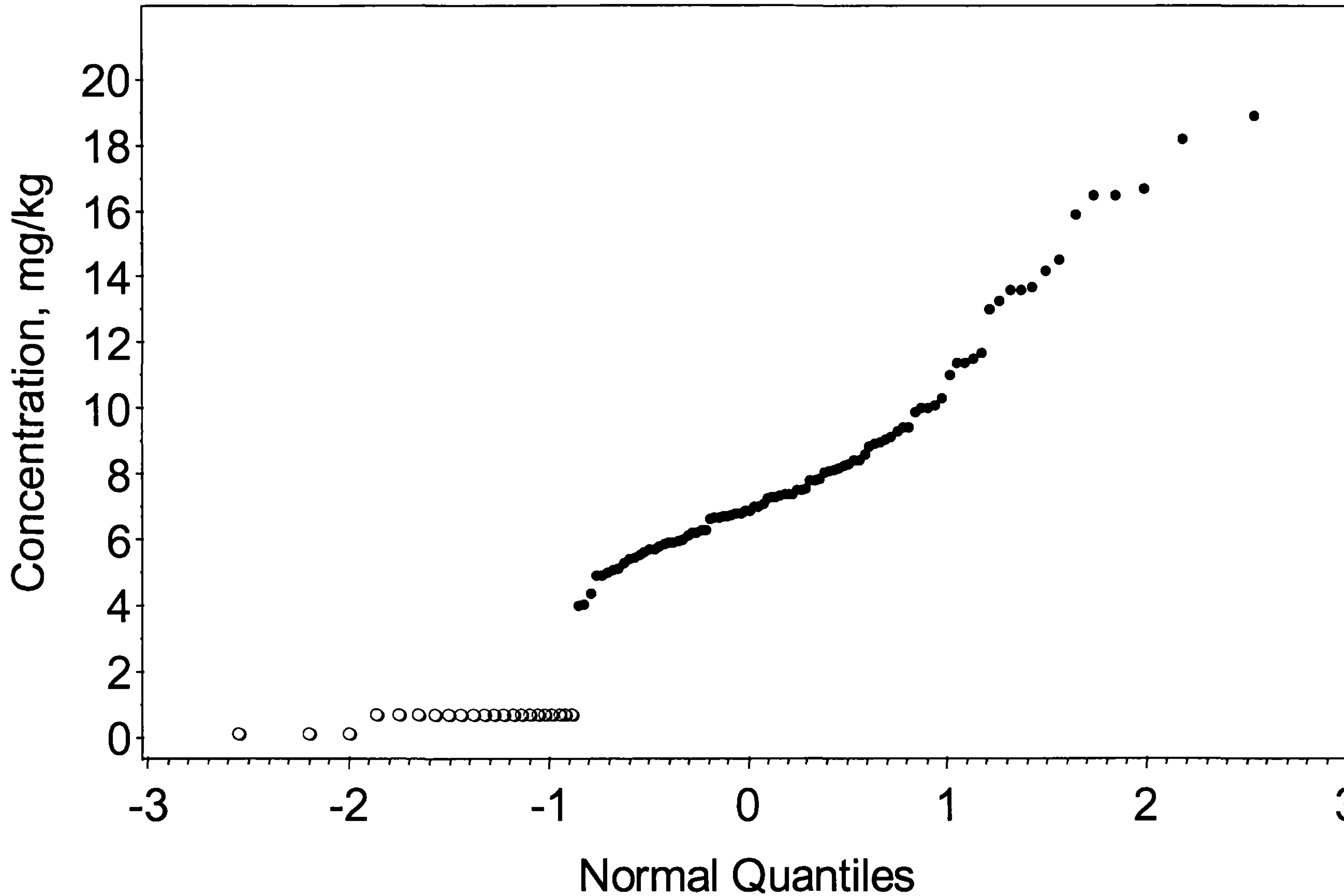
Sample Name	Arsenic Concentration (mg/kg)	Qualifier
NS09B_1998_1_2	7.5	
NS12B_1998_1_2	7.4	
SB-021_2005_NA_NA	7.40	
HA-08-S-00_5/13/2008_0_2	7.39	
SB-014_2005_NA_NA	7.33	
SS-219G-2_2001_0_1	7.3	J
SB-002_2005_NA_NA	7.28	
SB-015_2005_NA_NA	7.25	
NS05B_1998_1_2	7.1	
SB-012_2005_NA_NA	7.01	
CSS-004_2005_0_1	7	
SB-003_2005_0_1	6.89	
SB-016_2005_NA_NA	6.86	
CSS-010_2005_0_1	6.80	
SB-010_2005_NA_NA	6.79	
SS-227J-1_2001_0_1	6.74	J
SS-218A-3_2001_0_1	6.71	
CSS-011_2005_0_1	6.7	
SS-219A-2_2001_0_1	6.67	J
SS-218C-1_2001_0_1	6.65	
SS-219G-3_2001_0_1	6.63	J
NS13B_1998_1_2	6.3	
CSS-002_2005_0_1	6.3	
CSS-007_2005_0_1	6.20	
CSS-005_2005_0_1	6.20	
SB-011_2005_NA_NA	6.12	
SB-018_2005_NA_NA	6.02	
HA-04-S-00_5/13/2008_0_2	5.94	
HA-09-S-00_5/13/2008_0_2	5.9	
CSS-001_2005_0_1	5.9	
SB-019_2005_NA_NA	5.87	
CSS-009_2005_0_1	5.79	
SB-017_2005_NA_NA	5.73	
CSS-008_2005_0_1	5.70	
SB-001_2005_NA_NA	5.65	
CSS-006_2005_0_1	5.55	
HA-16-S-00_5/13/2008_0_2	5.47	
SB-005_2005_NA_NA	5.40	
NS09A_1998_0_1	5.3	
SS-227M-1_2001_0_1	5.12	J
SS-219G-1_2001_0_1	5.1	J
NS02B_1998_1_2	5	
SS-219A-3_2001_0_1	4.93	
SS-219J-1_2001_0_1	4.93	J
SS-220-4_2001_0_1	4.38	J
SB-022_2005_NA_NA	4.04	
CSS-003_2005_0_1	4	

TABLE 1
Arsenic Concentrations in Soil Samples
Feasibility Study Report—St. Louis Ordnance Plant, Former Hanley Area, St. Louis, Missouri

Sample Name	Arsenic Concentration (mg/kg)	Qualifier
PW13_2001_7_8	1.376	U
SS-218B-1_2001_0_1	1.376	U
SS-218B-2_2001_0_1	1.376	U
SS-218C-2_2001_0_1	1.376	U
SS-218C-3_2001_0_1	1.376	U
SS-219A-1_2001_0_1	1.376	U
SS-219D-1_2001_0_1	1.376	U
SS-219D-2_2001_0_1	1.376	U
SS-219D-3_2001_0_1	1.376	U
SS-219H_2001_0_1	1.376	U
SS-220-1_2001_0_1	1.376	U
SS-220-2_2001_0_1	1.376	U
SS-227B-1_2001_0_1	1.376	U
SS-228D-1_2001_0_1	1.376	U
SS-228F-1_2001_0_1	1.376	U
SS-228G-1_2001_0_1	1.376	U
SS-228M-1_2001_0_1	1.376	U
SS-228WX-1_2001_0_1	1.376	U
SS-228YZ-1_2001_0_1	1.376	U
SS47B_1991_1_2	0.25	U
SS48B_1991_1_2	0.25	U
SS51B_1991_1_2	0.25	U

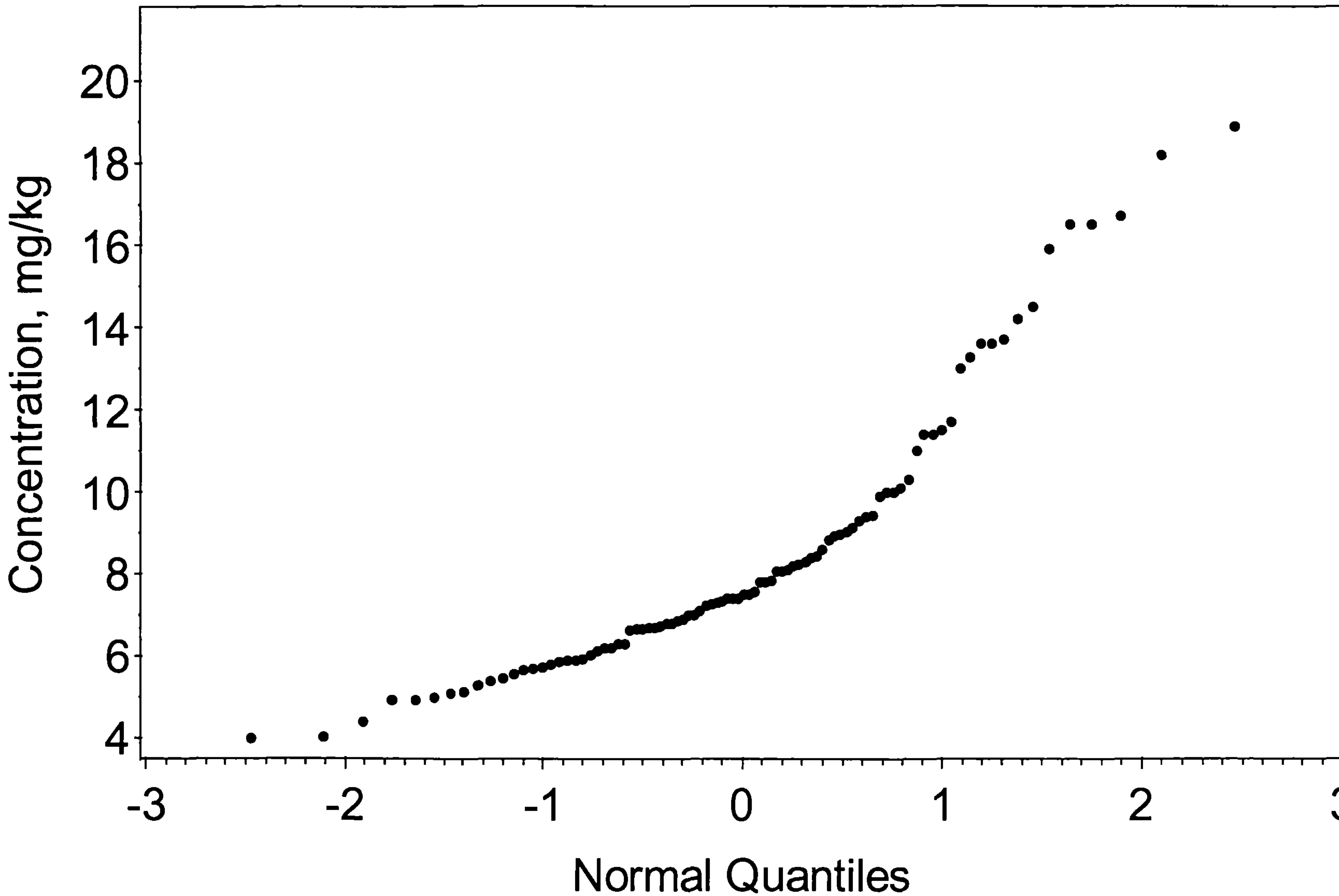
U = Chemical not detected
J = Reported value is estimated

EXHIBIT 1
Probability Plot for Raw Arsenic Results *



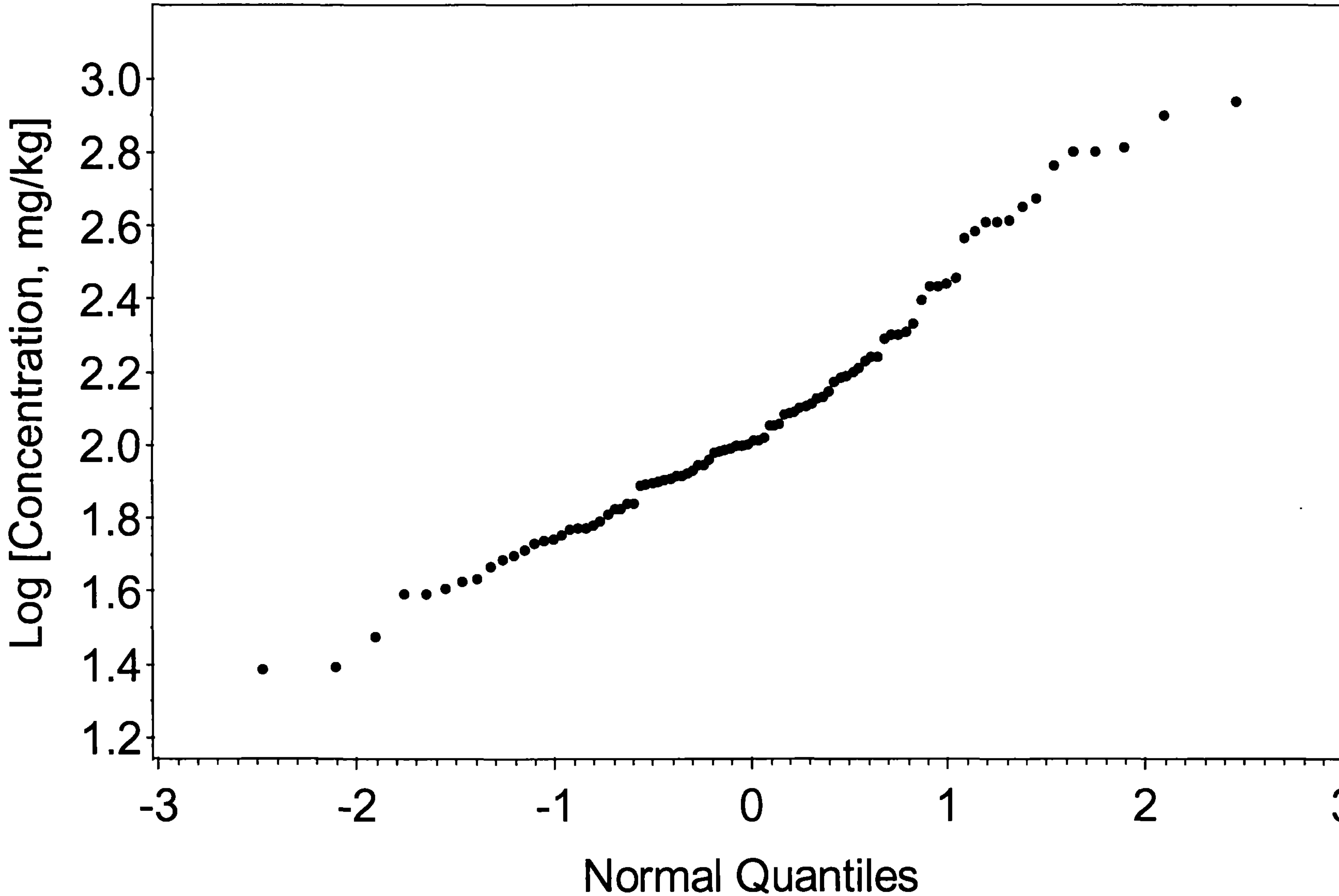
*after removal of two elevated outliers

EXHIBIT 2
Probability Plot for Raw Arsenic Detected Results *



*after removal of two elevated outliers

EXHIBIT 3
Probability Plot for Log-Transformed Arsenic Detected Results *



*after removal of two elevated outliers